Enhanced Wet Deposition of Nitrogen Induced by a Landfalling Typhoon over East Asia

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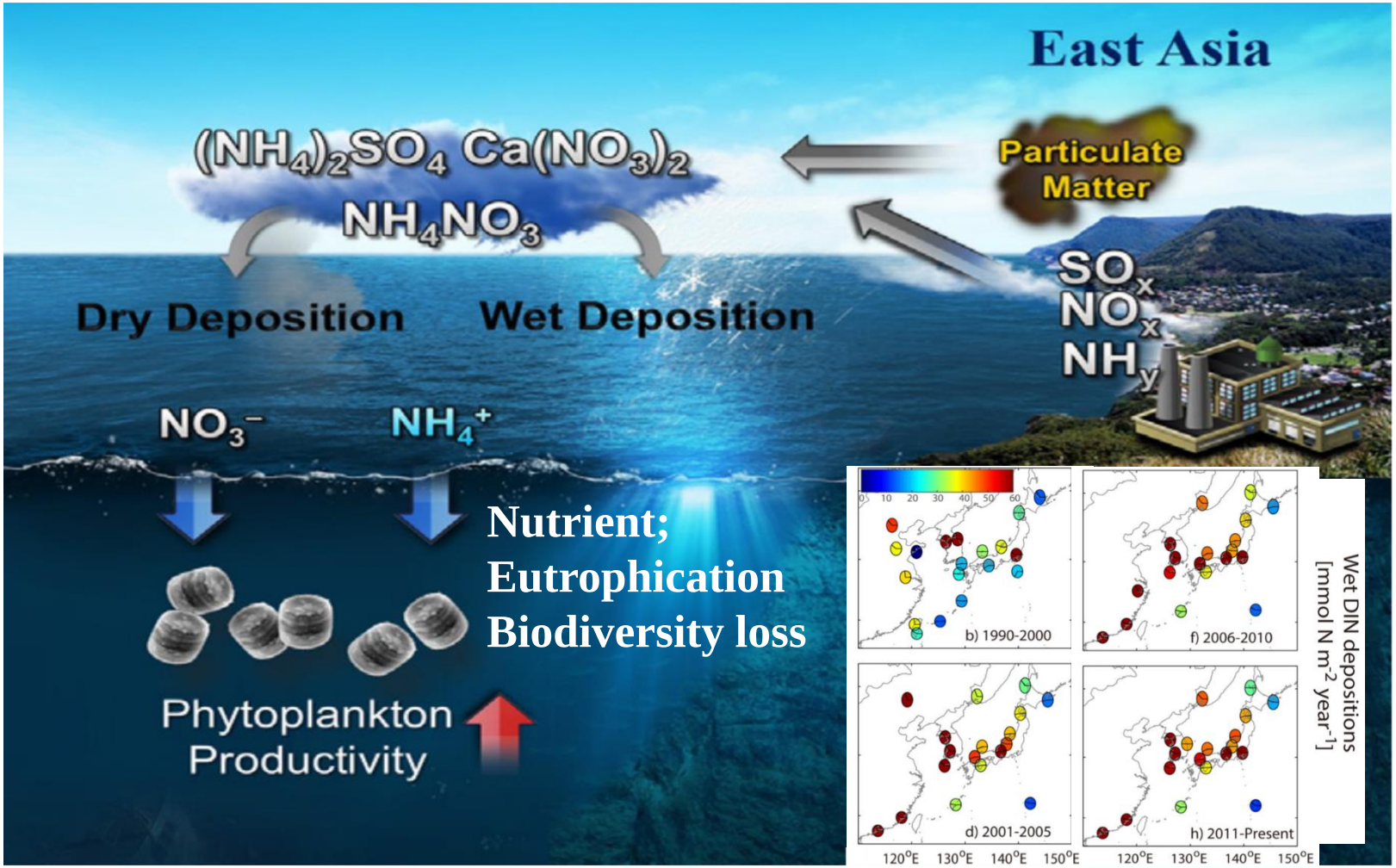
Important impacts of coastal emissions on the ocean

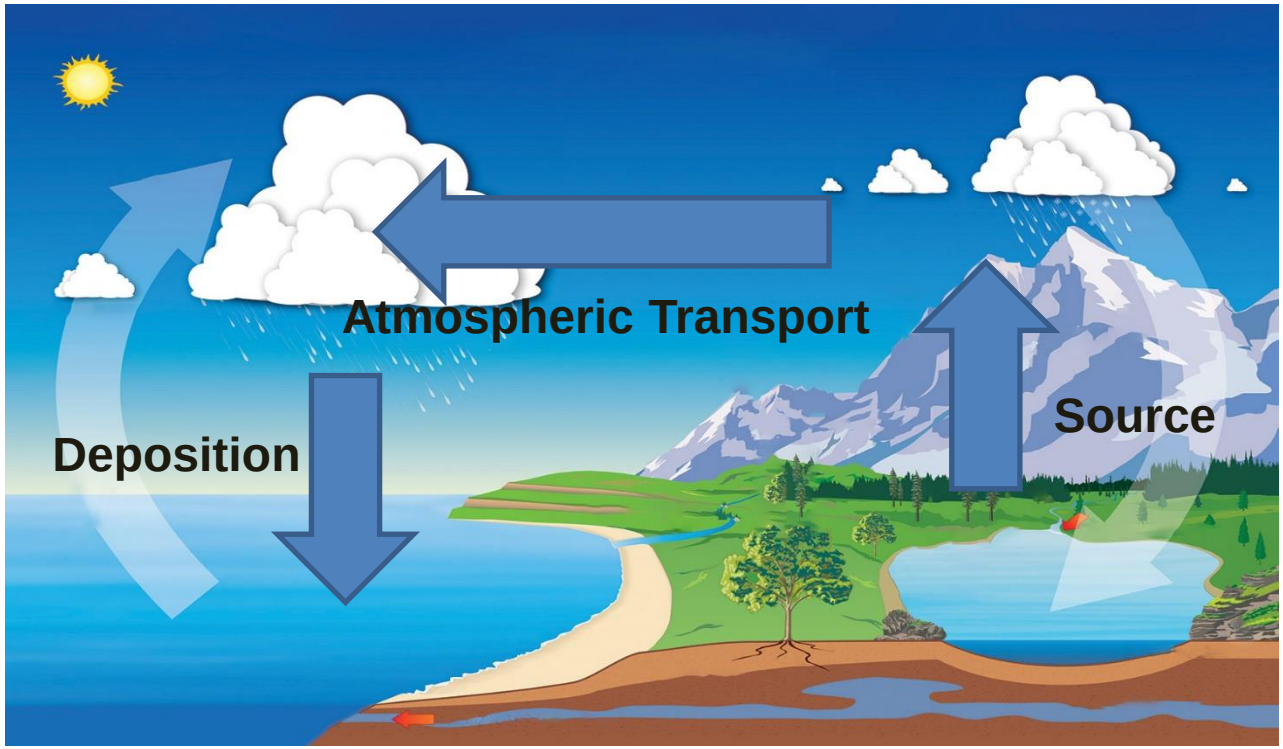
More than1/3 Oceanic N input were from Atmospheric deposition



Park et al., 2019, STE

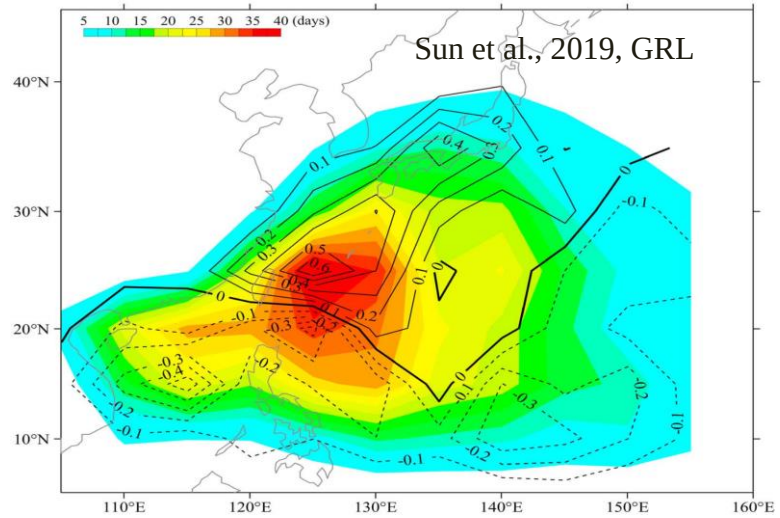
The ways of oceanic N input from atmospheric deposition

- Common cases: Dry deposition and Wet deposition
- Extreme weather events: Dust storm, Typhoon, etc
- High impacts: Fast and Significant to biodiversity risk

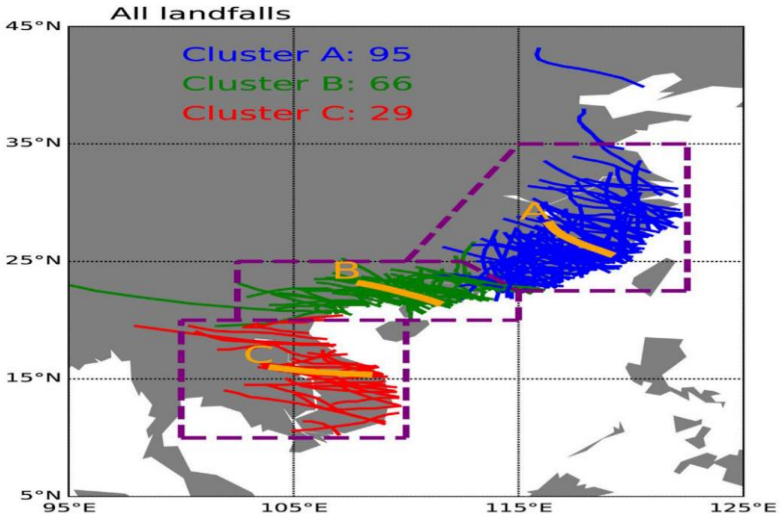


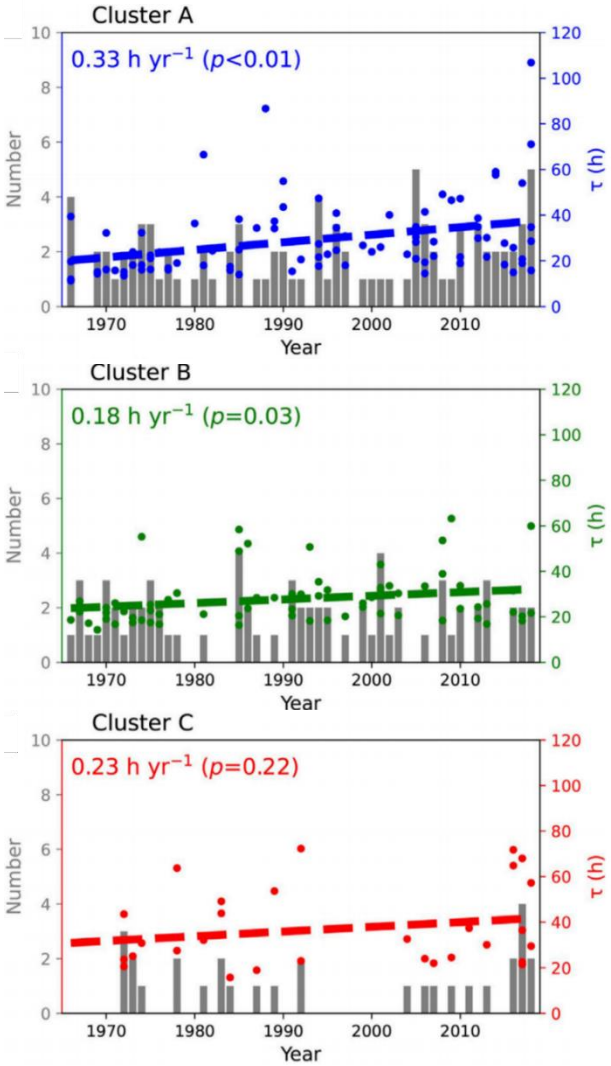
Typhoon landfalling in East China is increasing

tropical cyclone from 1982-2018



Sun et al., 2019, GRL

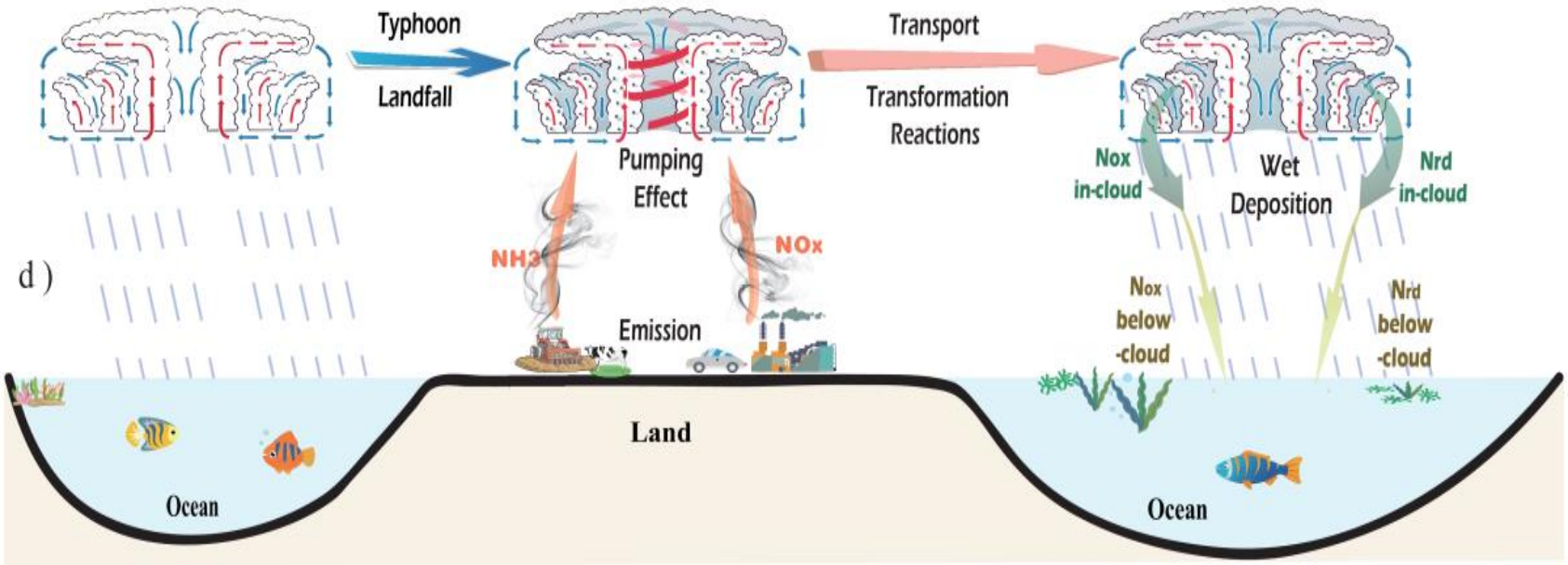




Song et al., 2021, FES

What happened to N deposition in Typhoon landfalling

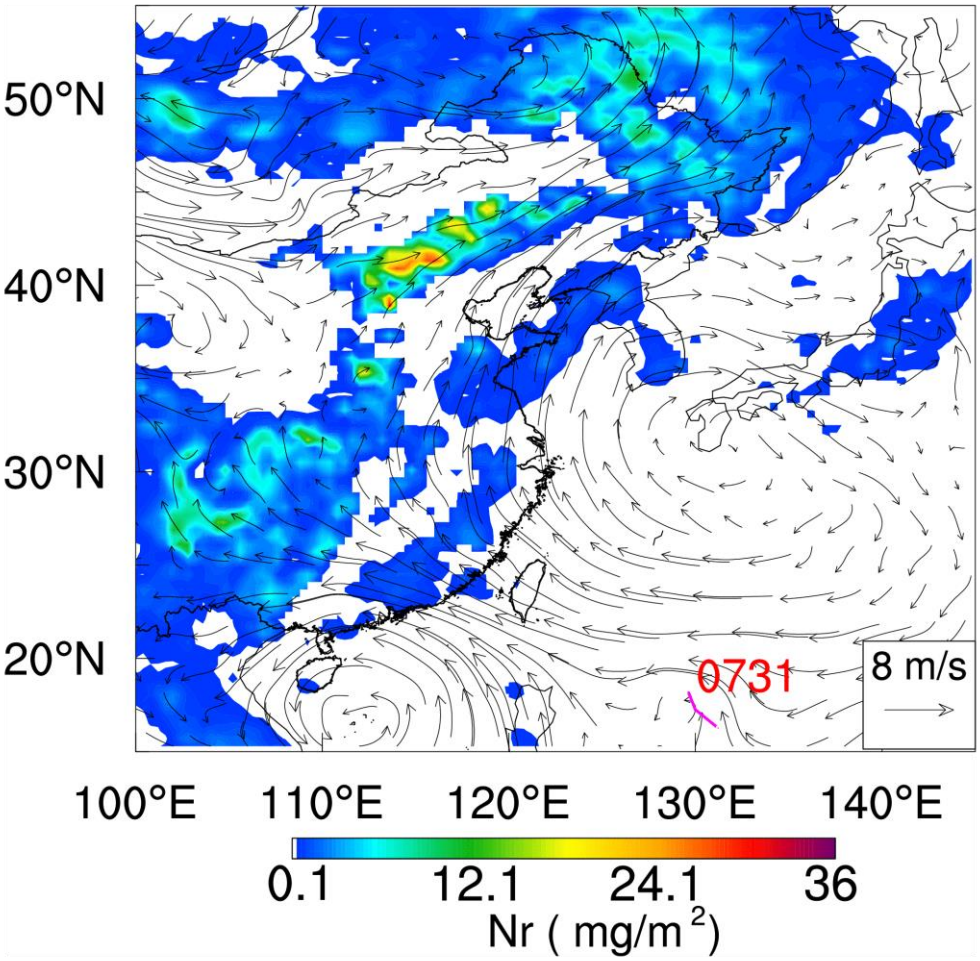
Heavy rain; Fast moving -> long range transport



Mechanism "Pumping effect":

Deep convective transports associated with cyclones are significant, which uplifted the Nr emitted at ground level into free troposphere and subsequent transported as well as deposited through the cyclone's counterclockwise motion to downwind areas.

A typical case of Typhoon Hagupit



Typhoon Hagupit (2020.0801~0806)

- Pre-landfall (1–2 August),
- Landfall (3–4 August)
- Post-landfall (5–6 August)

Landfall region：YRD

Model setup and data source

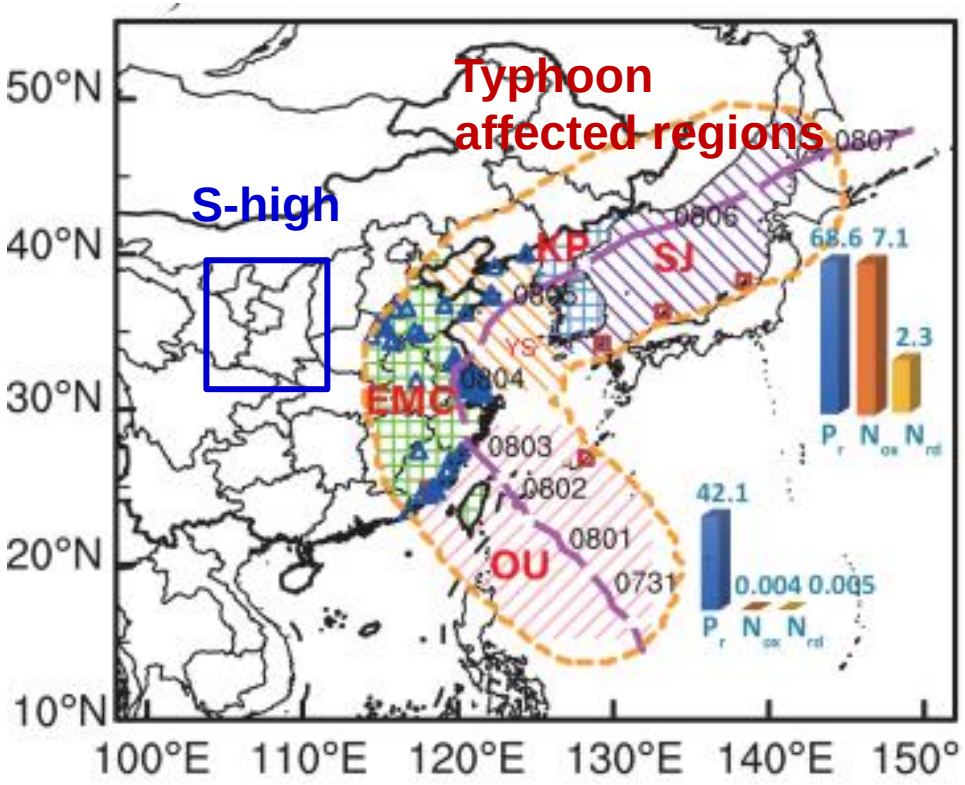
WRF模式参数化配置

参数化	设置
水平网格	182×172
垂直层	36
水平分辨率（km）	45
时间步长（s）	180
积分时间（hour）	36
自适应时间（hour）	12
模拟输出（minute）	60
积云对流参数化方案	Tiedtke
短波辐射方案	RRTMG
长波辐射方案	RRTMG
边界层方案	YSU
初始和边界条件	NCEP-FNL
微物理参数化方案	WDM6

NAQPMS模式参数化配置

参数化	设置
平流输送	高精度正定质量守恒差分格式方案计算（Walcek and Aleksic, 1998）
湍流扩散	梯度输送，水平（王自发，1997）；垂值（Byun and Dennis，1995）
干沉降过程	气体Wesely（1989）方案；气溶胶Slinn 等（1980）方案
湿沉降过程	云内沉降Ge et al.(2019)；云下沉降Xu,et al.(2020).
气相化学过程	CBM-Z（Zaveri and Peters, 1999）
气溶胶物理化学过程及非均相反应	气溶胶热力学模式 ISORROPIA（Nenes et al., 1998, 1999）；气溶胶表面非均相化学反应28个（Li et al., 2012）
初始和边界条件	MOZART v2.4提供
排放源	来源于MICS-Asia III (Li et al., 2017)并使用NH_3和NO_x的卫星柱浓度限制

Model setup and data source



Wet deposition of N：

- 中国国家环境监测中心(CNEMC)
- 东亚酸沉降监测网络(EANET)

$N_{ox} = HNO_3 + NO_x + NO_3^-$ $N_{rd} = NH_3 + NH_4^+$

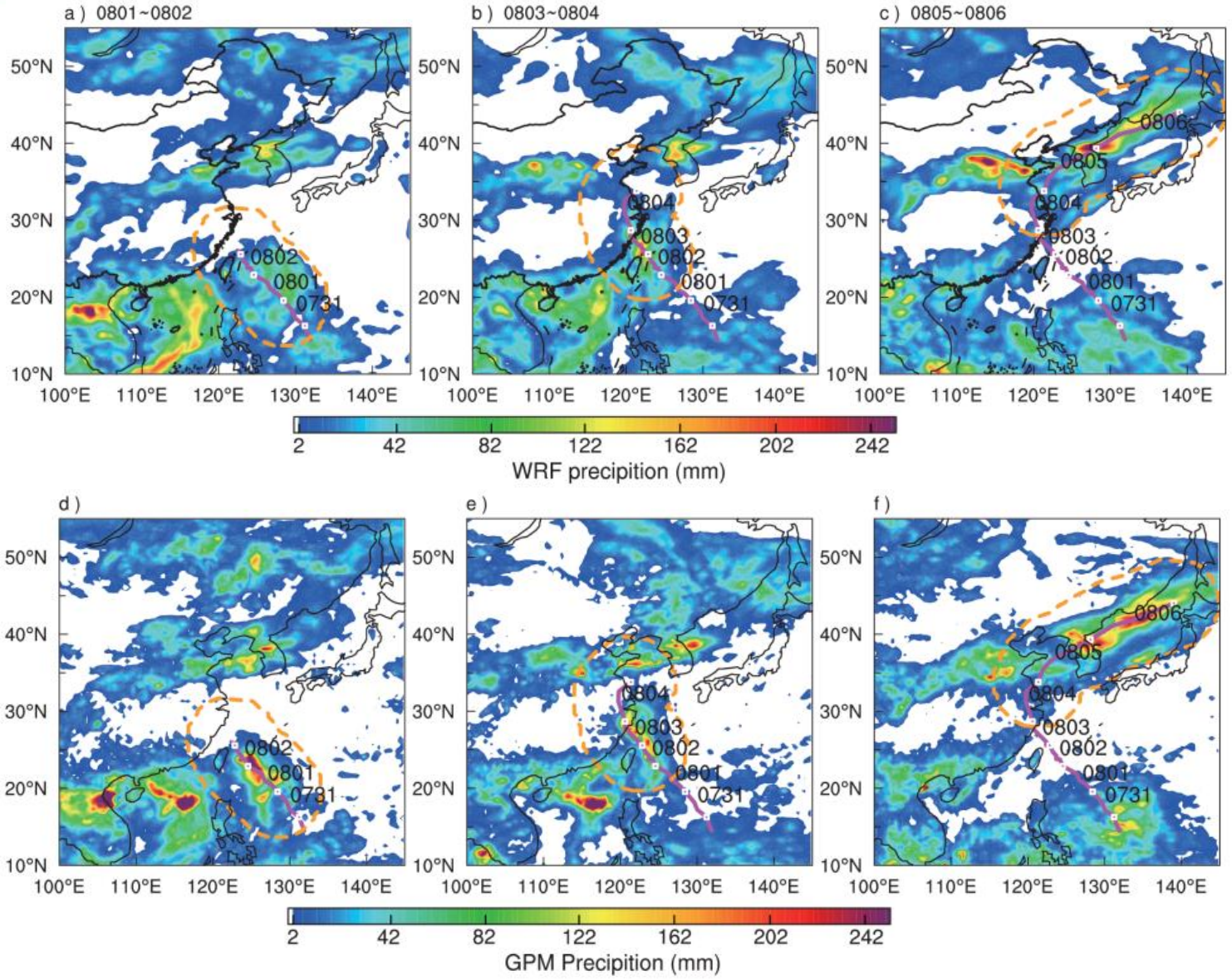
Marine Ecological Response：

- GBAF chlorophyll-a concentration from Copernicus Marine Service (CMEMS)

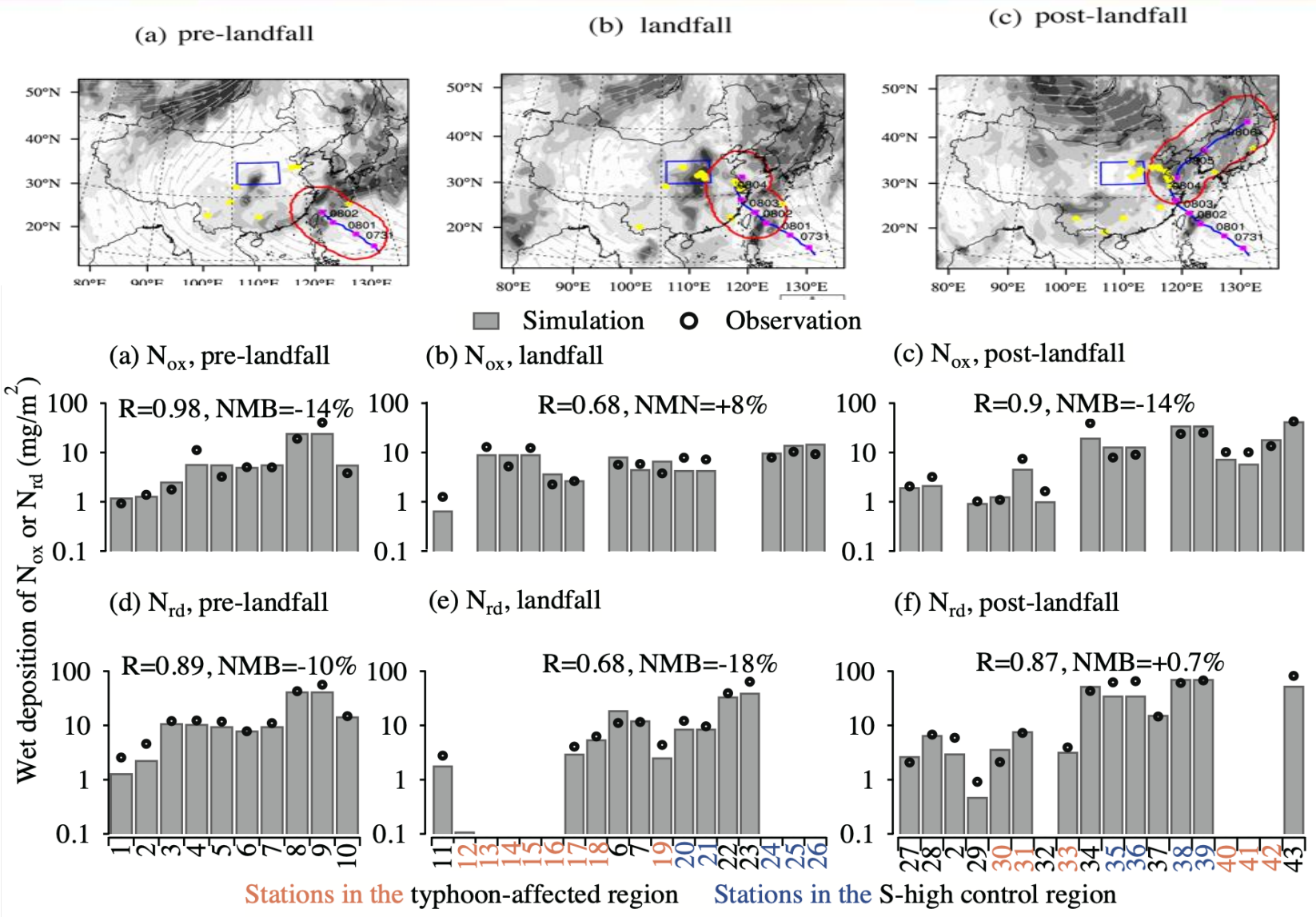
Precipitation：

- Satellite data GPM-IMERG
- Ground station of CMA

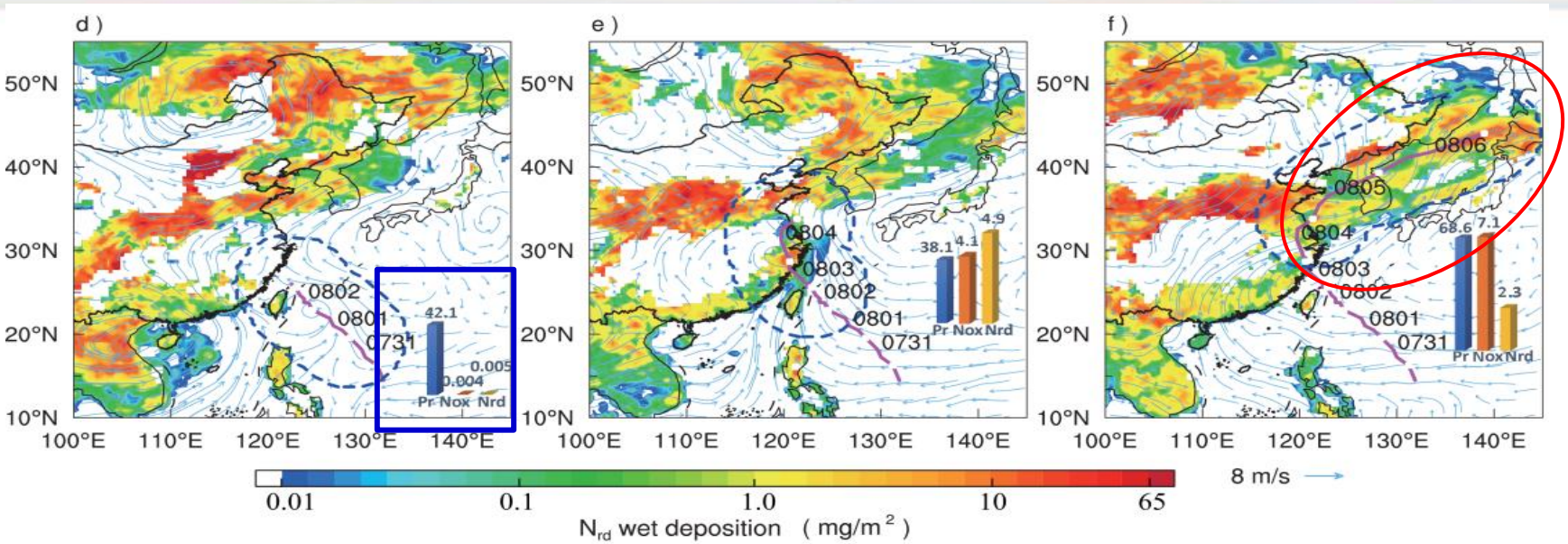
Good performance in Typhoon track and precipitation



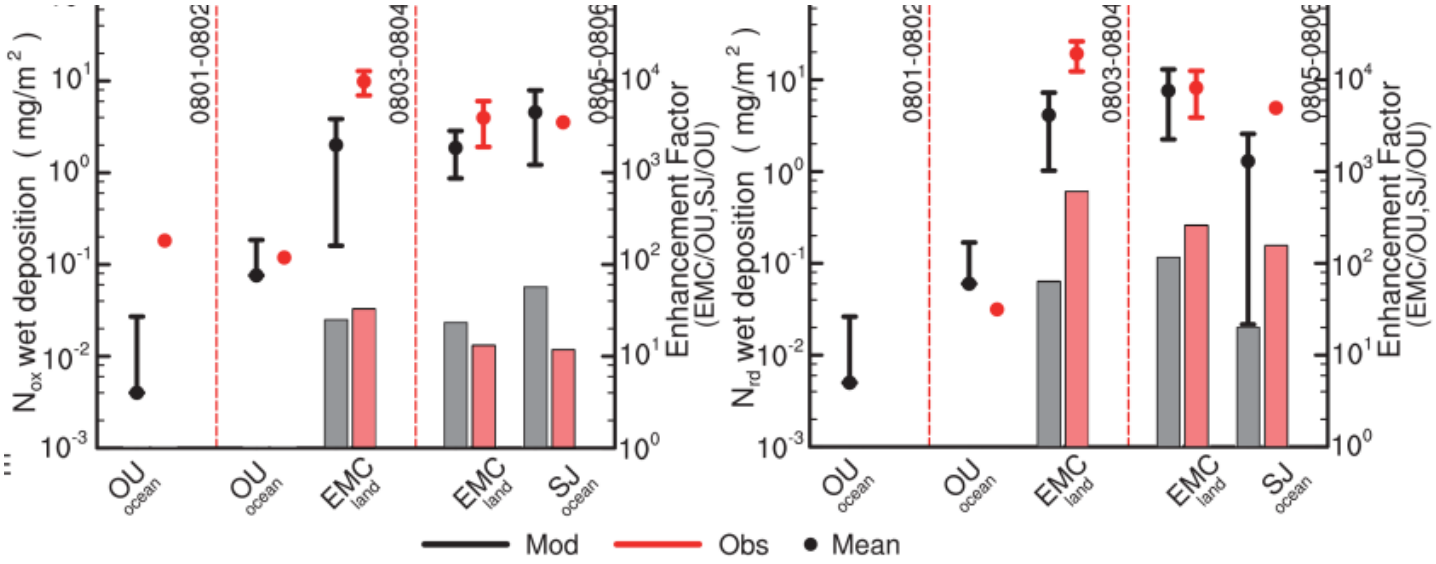
Validation of simulation wet deposition by CNEMC and EANET



Significant increasing of N_{ox} and N_{rd} deposition during landfall and post landfall

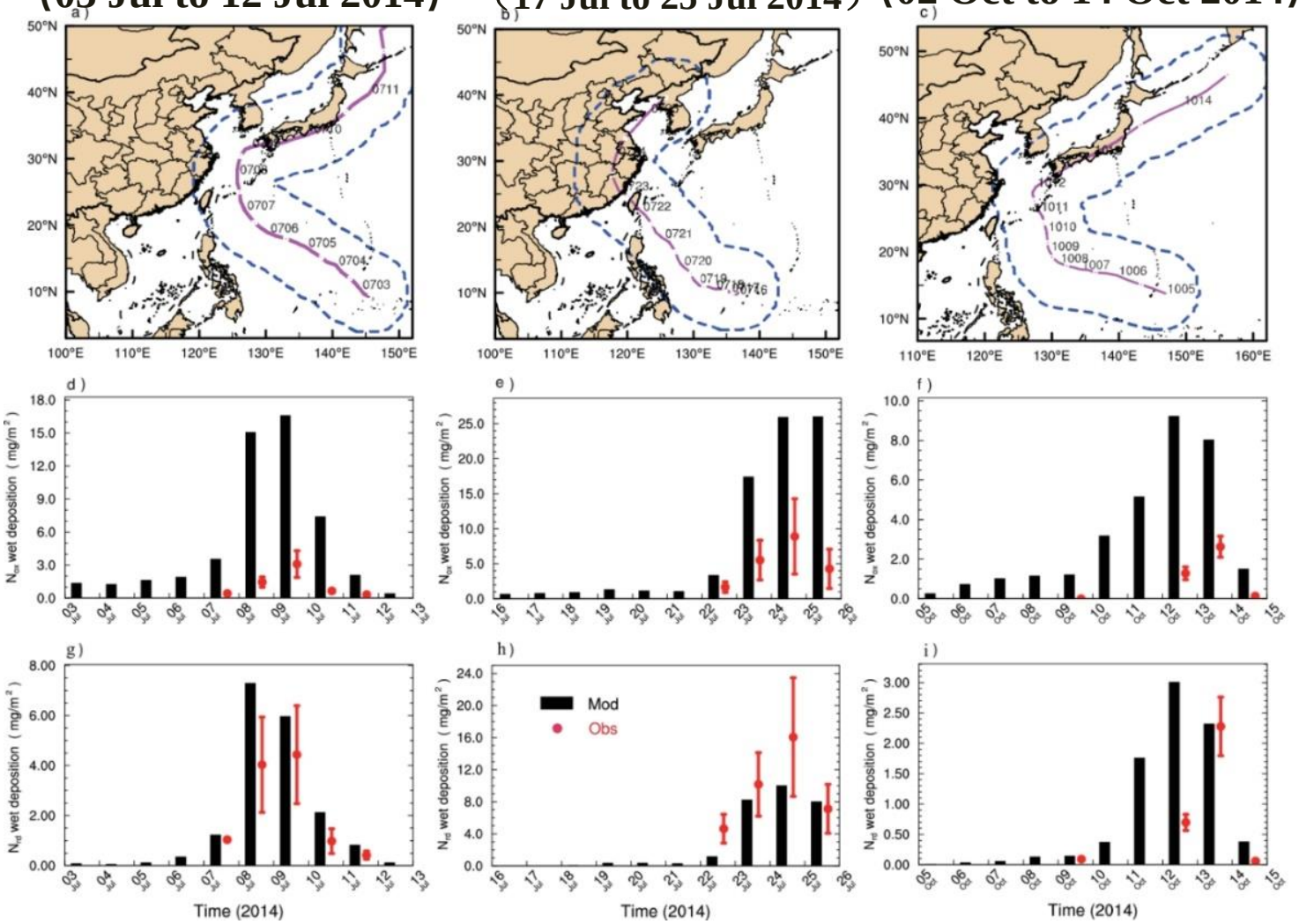


- **Similar rainfall**
- **~1000 times enhancement**



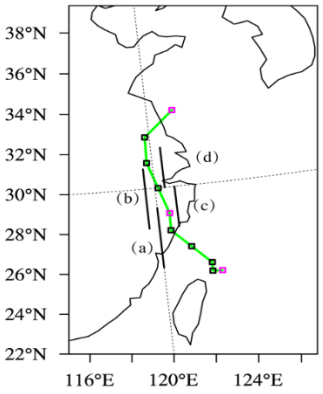
Similar characteristics in other typhoon cases

NEOGURI (03 Jul to 12 Jul 2014) | **MATMO (17 Jul to 25 Jul 2014)** | **VONGFONG (02 Oct to 14 Oct 2014)**

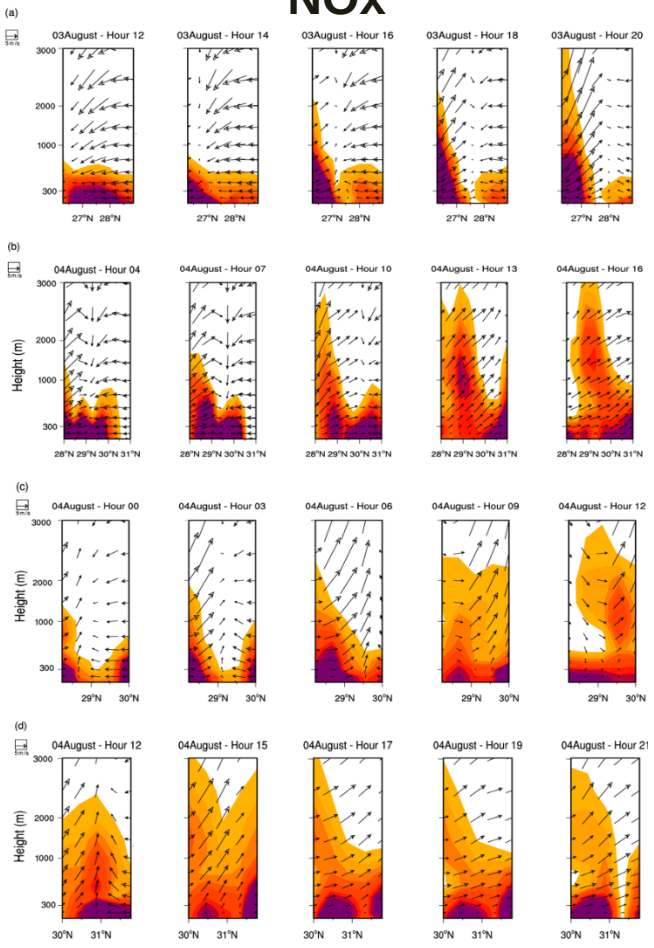


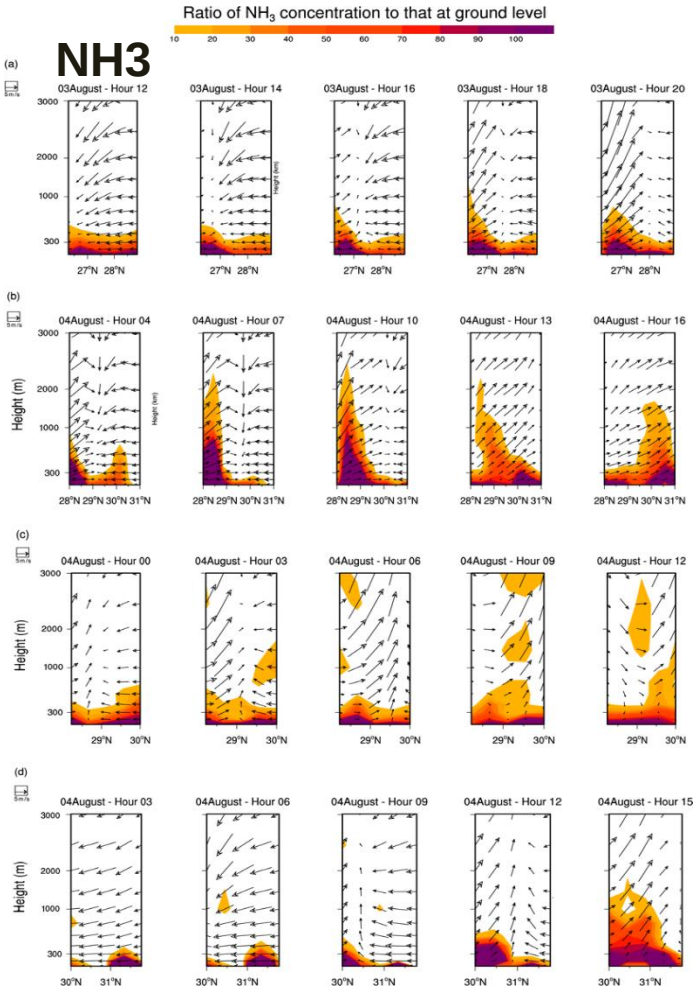
Typhoon's pumping effect: uplift

Boundary layer turbulent mixing (limited 0.6-0.8 km)
The cold-front structure of most cyclones (1-2.5 km)
Typhoon uplift (3-4 km)



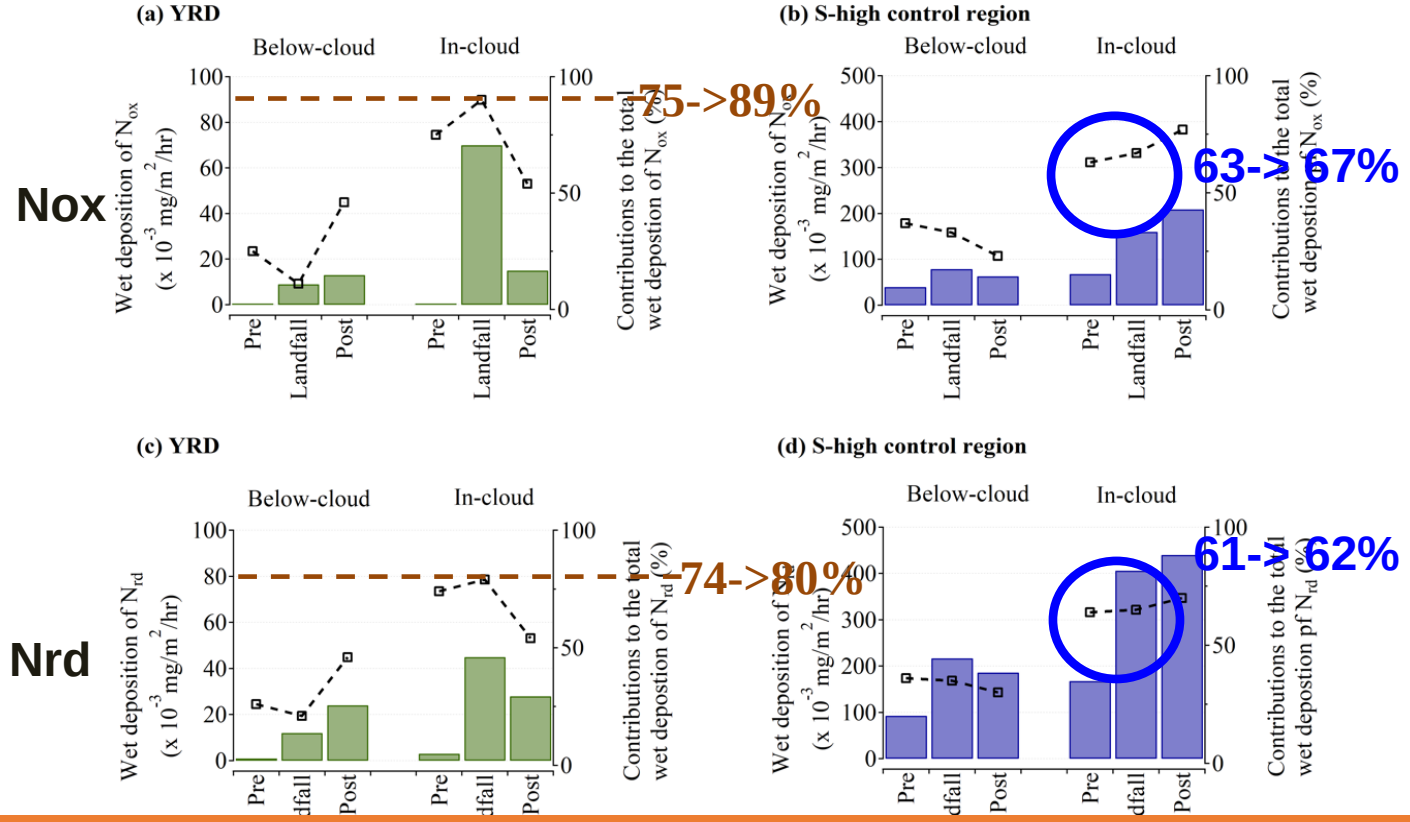
(a) Lon = 120°E, Lat = 26°N-29°N
(b) Lon = 119.5°E, Lat = 28°N-31°N
(c) Lon = 120°E, Lat = 28°N-30°N
(d) Lon = 120.5°E, Lat = 30°N-32°N





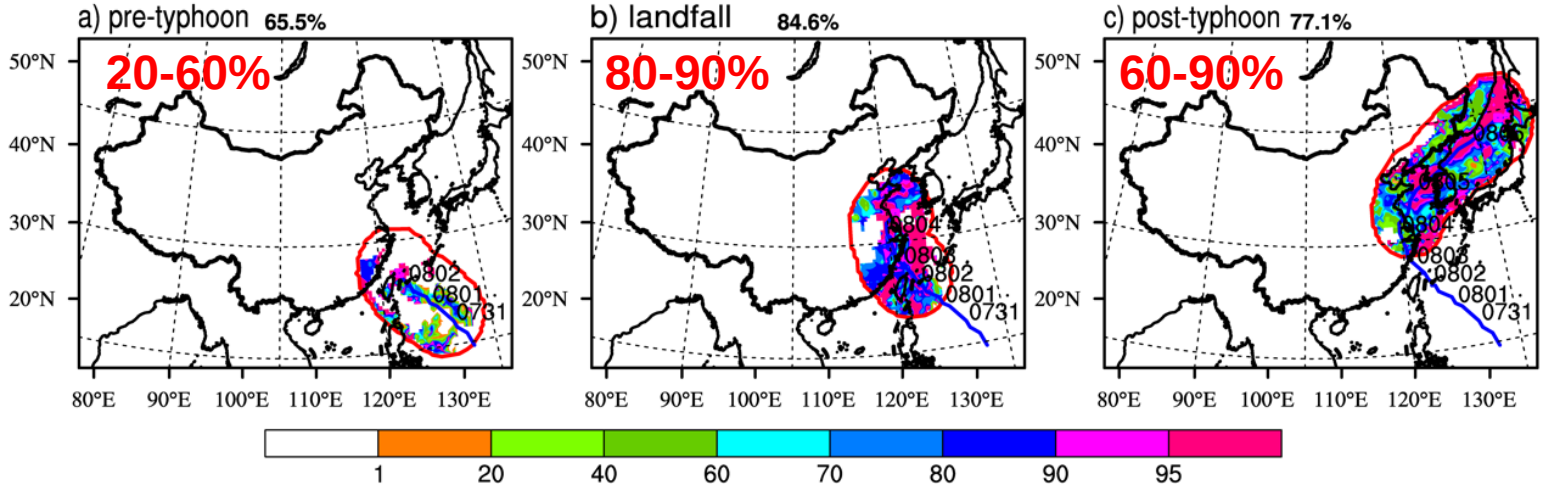
Typhoon's pumping effect：Deposition from in cloud

- In YRD, in-cloud wet deposition contributions was increased (89% for oxidized N wet deposition)
- 39%-53% during 2014-2017 observed in China (Ge et al., 2021) and 34% observed in Japan (Aikawa & Hiraki, 2009; Aikawa et al., 2014)

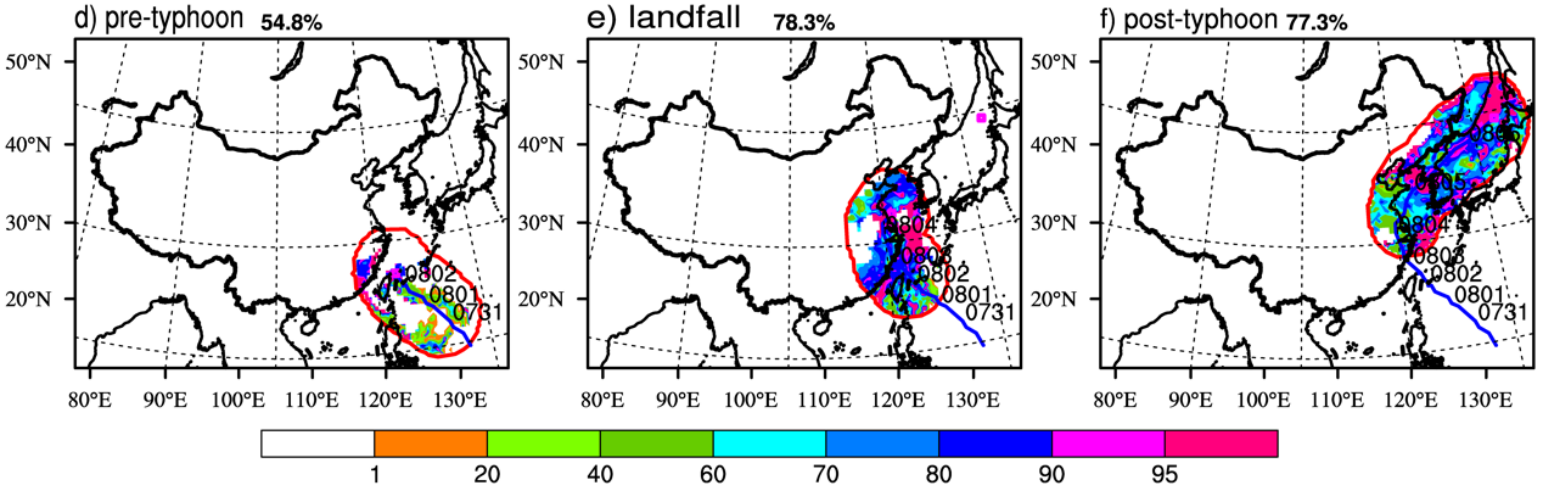


Pumping effect helps to get more N into clouds to be transported and scavenged

Increasing impacts of in-cloud scavenging during landfall

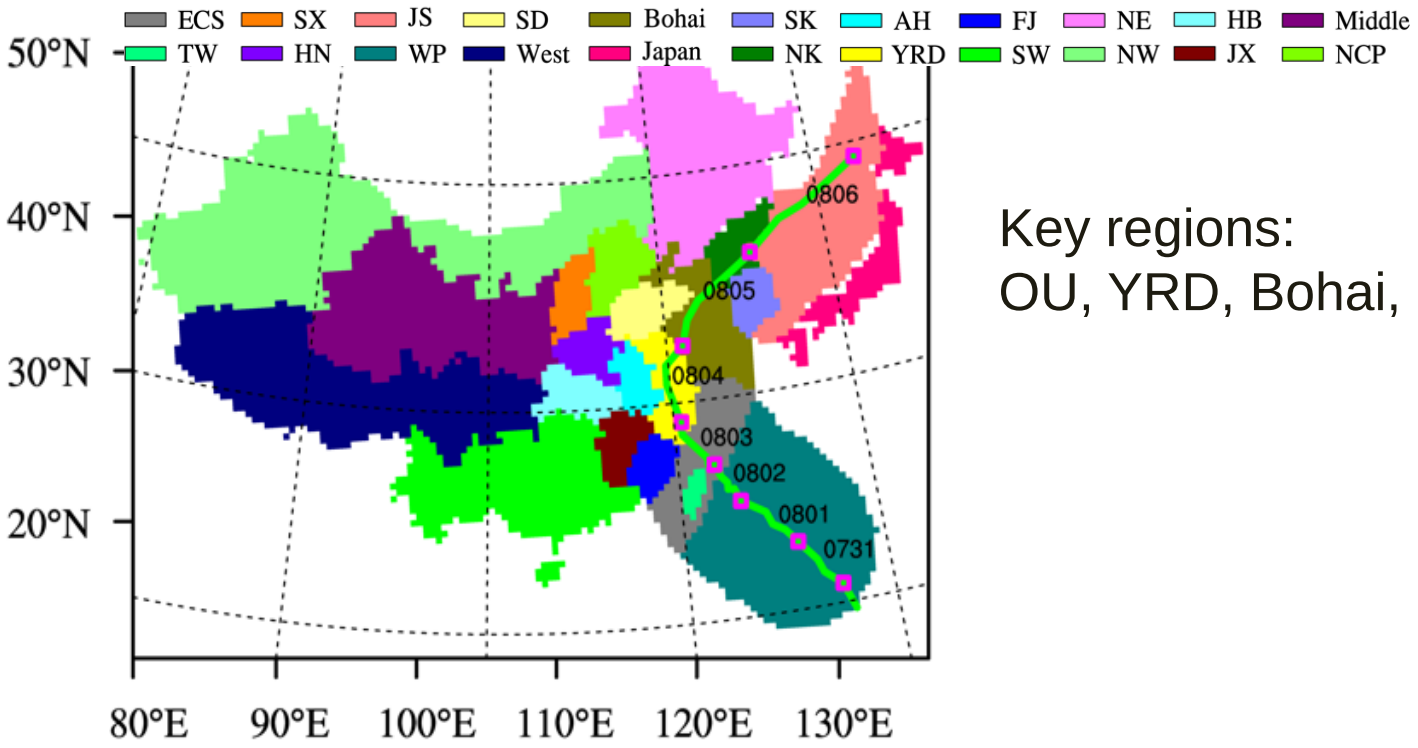


N_{ox} in-cloud wet deposition ratio in the typhoon-affected region (%)



N_{rd} in-cloud wet deposition ratio in the typhoon-affected region (%)

Source Tracking method in wet scavenging



Key regions:
OU, YRD, Bohai, SK, JS, Japan

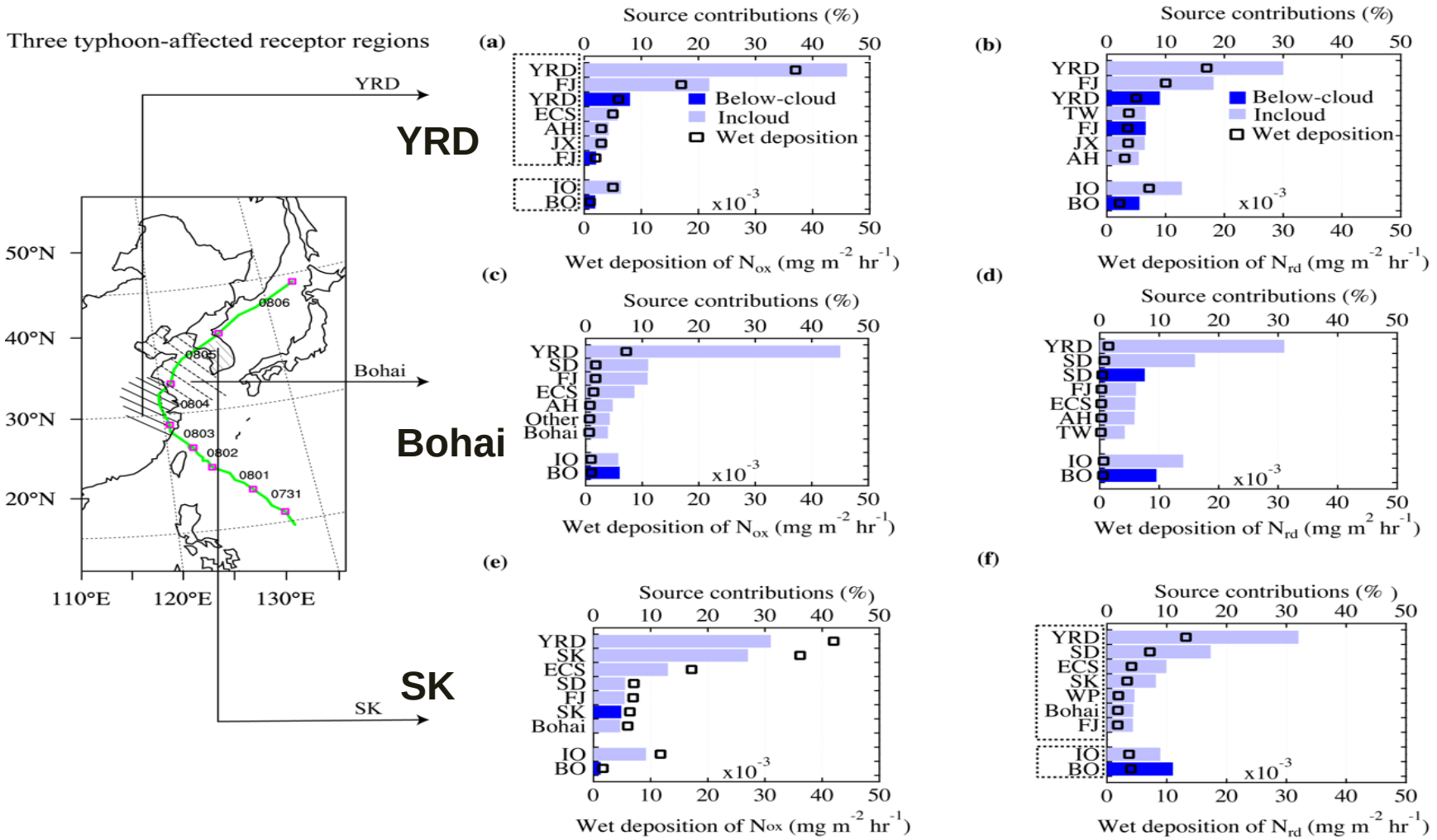
$$BDep(ID_i, ID_j, S) = \frac{\sum_{m=1}^{m=N}\sum_{t=1}^{t=T} Bdep_m(ID_i, Sp_k, t) \times BContri_m(ID_i, ID_j, Sp_m, t)}{\sum_{m=1}^{m=N}\sum_{t=1}^{t=T} dep_m(ID_i, Sp_m, t)}$$

$$IDep(ID_i, ID_j, Sp) = \frac{\sum_{m=1}^{m=N}\sum_{t=1}^{t=T} Idep_m(ID_i, Sp_m, t) \times IContri_m(ID_i, ID_j, Sp_m, t)}{\sum_{m=1}^{m=N}\sum_{t=1}^{t=T} dep_m(ID_i, Sp_m, t)}$$

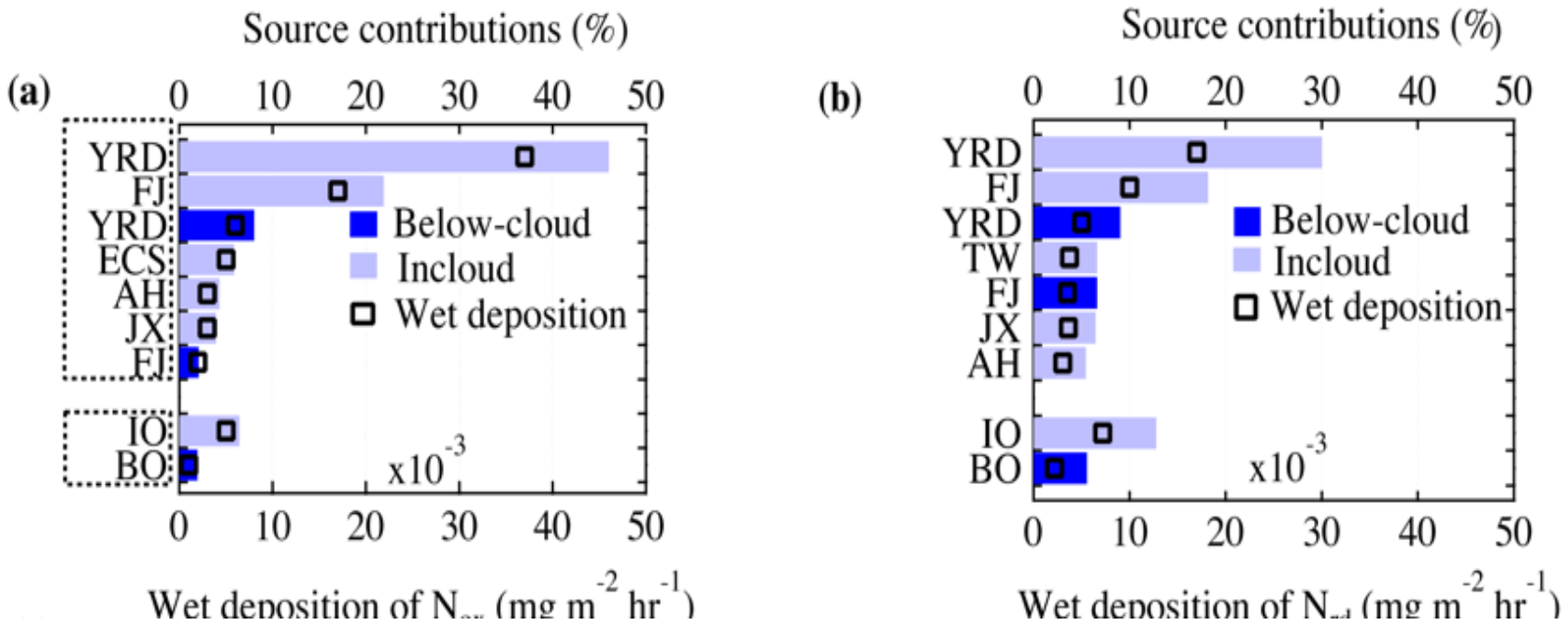
Typhoon's pumping effect: Transport in cloud

Three typhoon-affected regions a) YRD, b) Bohai and c) SK

Largest contribution was from YRD, the landfall region of Hagupit

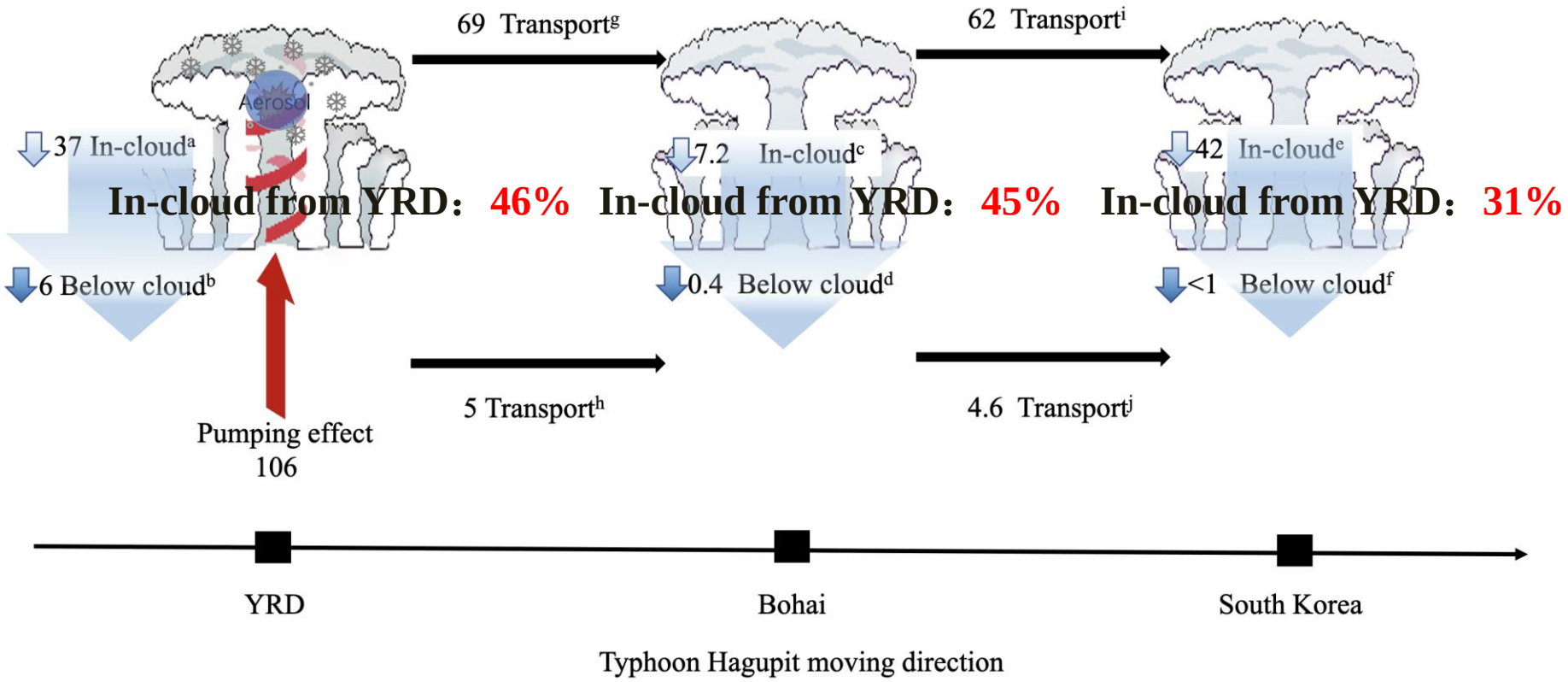


Local emission influence the in-cloud scavenging in YRD



This updated S/R relationship of in-cloud wet deposition during the typhoon event challenges the traditional view that the in-cloud wet deposition of acidic pollutants is mainly linked with long-range transport.

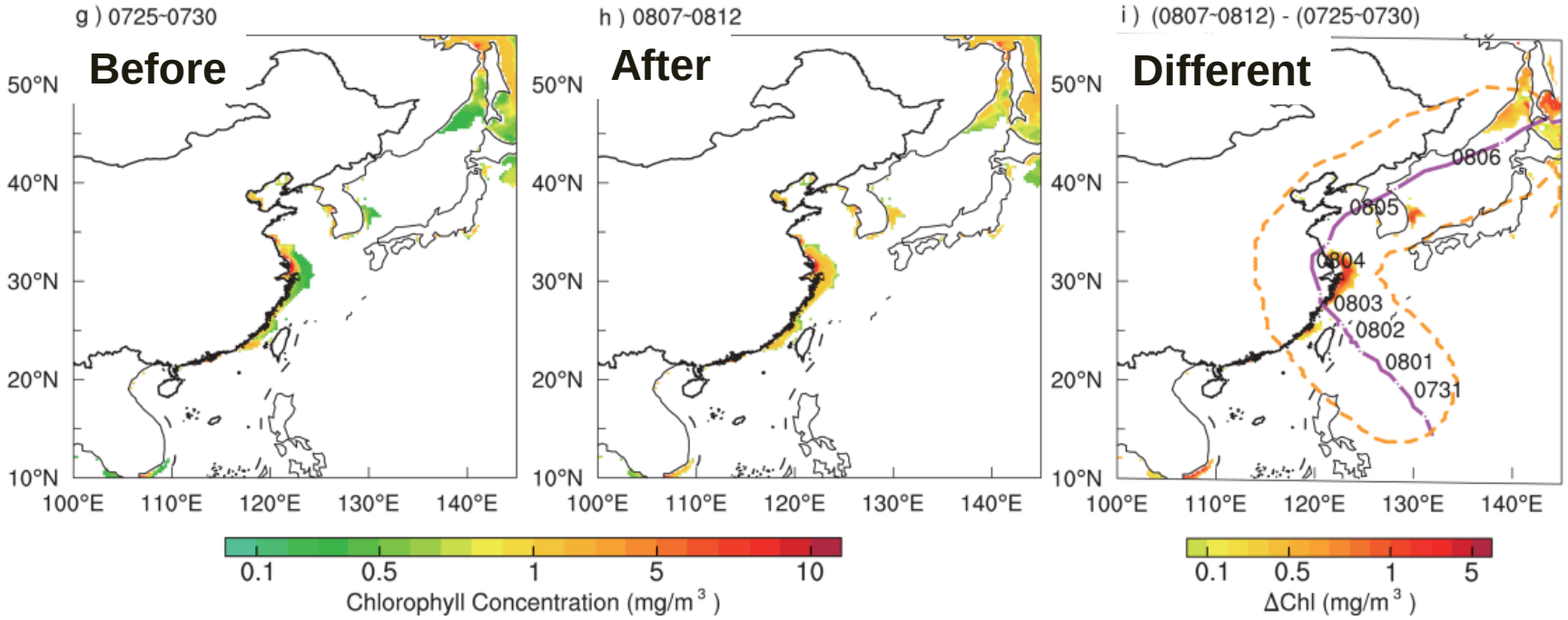
Source identification along the pathways



The wet deposition induced by the pumping effect would have a profound effect on the wet deposition in the typhoon-affected regions

Marine Ecological Response: phytoplankton blooms

Chlorophyll-a concentration before and after the typhoon's passage

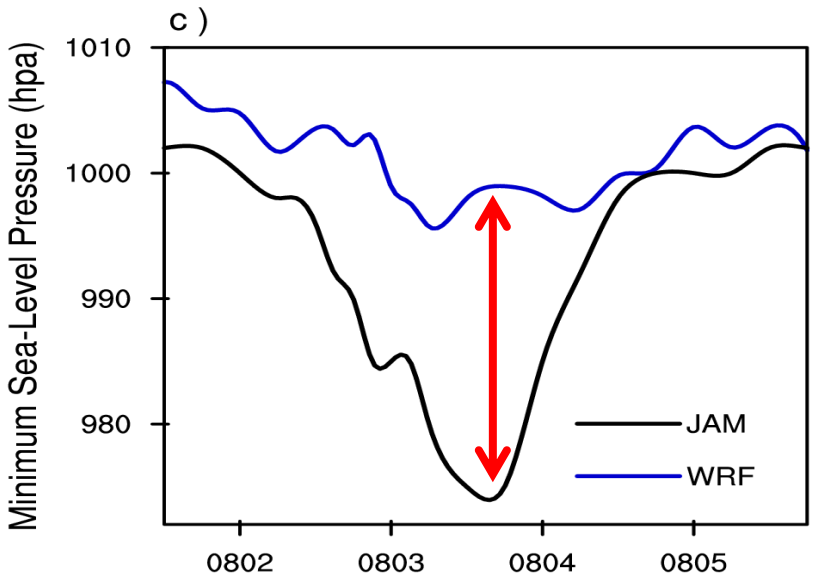


- **The Chl-a associated with landfalling typhoon–induced phytoplankton blooms was around 0.50~0.65 mg m−3, which was about 32%~73% higher than the pre-typhoon Chl-a levels**
- **Typhoon-induced wet deposition of Nr would then have created carbon fixation in the marine biological productivity of 12.67–25.44 mgC m−2 day−1 in YS and 26.8 mgC m−2 day−1 in SJ.**

Summary

1. Based on NAQPMS, it is clarified a “pumping effect” mechanism of landfalling typhoon, which uplift the air pollutants in the ground surface into the high altitudes, then transported and deposited via the in-cloud scavenging process.
2. The “pumping effect” would have profound effect on the wet deposition in the typhoon-affected regions, especially the coastal marine regions.
3. The landfalling area was the largest contributors to the deposition in the typhoon-affected regions.

Future perspectives



Underestimation of sea-level central pressure by WRF

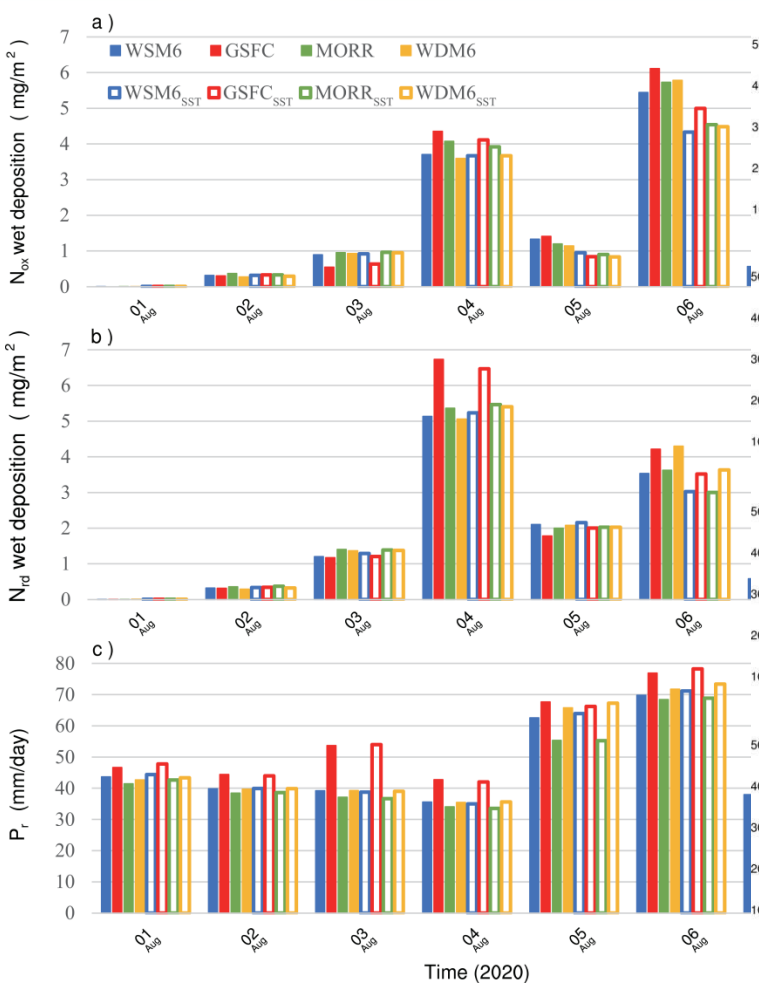
Possible reasons:

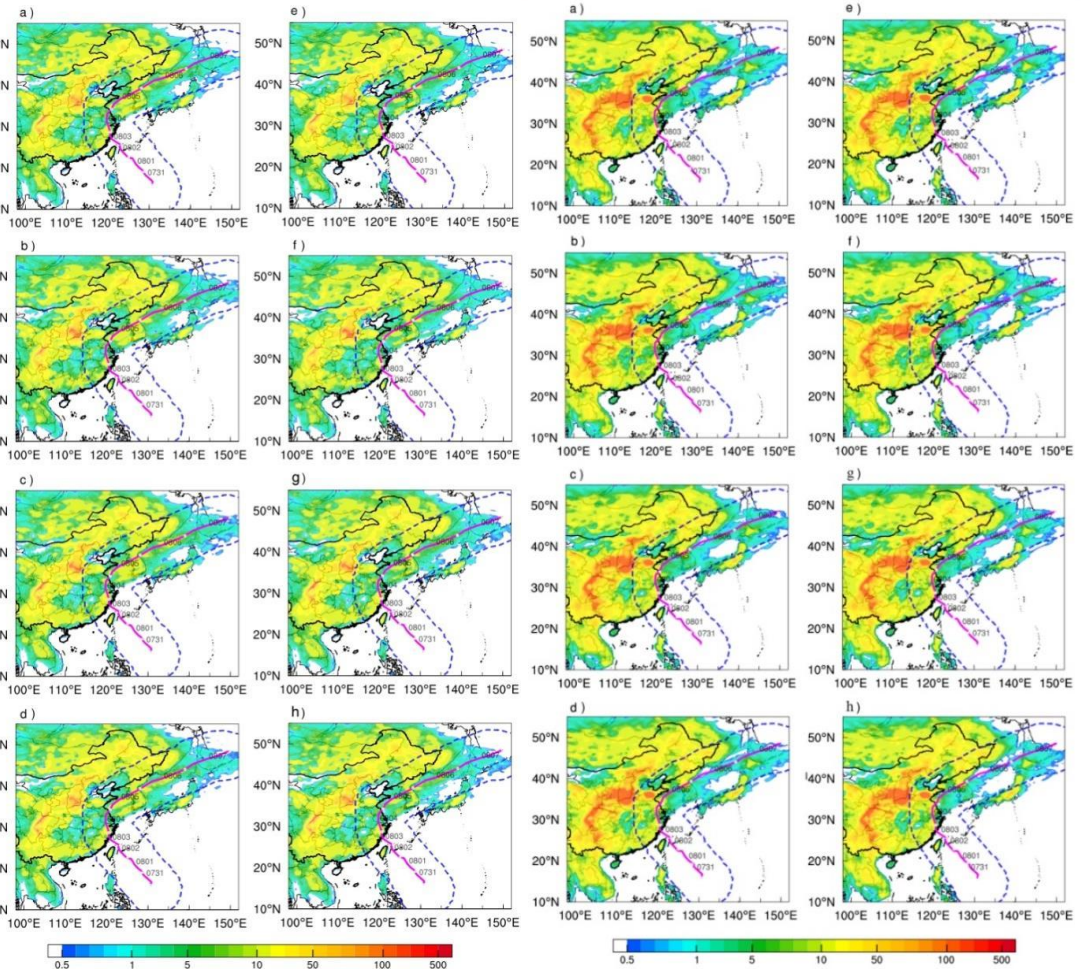
1. Resolution, high resolution
2. Cumulus parameter scheme
3. Feedback effects of ACI, ARI

ACI enhance intensity, while ARI on the contrary

1. On-line model should be considered to the feedback effects of the pollutants been captured by cloud droplets to the typhoon intensity
2. Multi-model comparisons in extreme weather events are needed, since these events have quick and significant impacts

Microphysics comparison: little difference





N_{ox} wet deposition **N_{rd} wet deposition**

Thank You

1. Zhang, Y., Su, X., Ge, B.*, Xu, X., Tan, Q., Chen, G., Xu, D., Chen, X., Wu, L., Gao, M., Pan, X., Guo, J., Liu, X., Fu, J. S., and Wang, Z.: Enhanced Wet Deposition of Nitrogen Induced by a Landfalling Typhoon over East Asia: Implications for the Marine Eco-Environment, Environ Sci Tech Let, 10.1021/acs.estlett.2c00762, 2022.
2. Qixin Tan, Baozhu Ge*, Syuichi Itahashi,Lu Gan, Ying Zhang, Shuyan Xie, Ying Liu, Danhui Xu, Xueshun Chen, Lin Wu, Xiaole Pan, Wei Wang, Jianbin Wu, Jie Li, Junhua Wang, Xiaobin Xu, Joshua S. Fu, Zifa Wang: Unexpected high contribution of in-cloud wet scavenging to nitrogen deposition induced by pumping effect of typhoon landfall in China, submitted to ERC (in review)

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