

Stratospheric Ozone Fraction in the Upper Troposphere from Daily Ozonesondes during the Asian Summer Monsoon

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Theme 2
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1. Motivation

The upper troposphere–lower stratosphere (UTLS) is a highly variable transition layer where stratospheric and tropospheric air are exchanged (Holton et al., Rev. Geophys., 1995; Stohl et al., JGR, 2003; Gettelman et al., Rev. Geophys., 2011). Intrusions of ozone-rich stratospheric air change upper-tropospheric composition, affecting radiative forcing (Riese et al., JGR, 2012), the tropospheric ozone budget (Škerlak et al., ACP, 2014), and even surface air quality (Lin et al., JGR, 2012). Over East Asia, such intrusions occur along the edge of the Asian summer monsoon anticyclone (Kang et al., JGR, 2025), but their depth and intensity are hard to quantify from ozone alone. We apply the Stratospheric Fraction (SF; Roy et al., JGR, 2023), which uses the O₃–H₂O relationship to place each air parcel on a 0–100% scale between moist, ozone-poor tropospheric air and dry, ozone-rich stratospheric air, to daily ozonesonde profiles.

Q: Can an O₃–H₂O tracer diagnostic (SF) quantify the depth and intensity of stratospheric intrusions observed by ozonesondes?

2. Data

Table 1. The data used in this study.

Ozonesonde	Site	Location	Year	Vertical res.
	Anmyeon	36.54°N 126.33°E	2021 – 2022	100 m
MERRA-2	Name	Resolution	Reference	
	M2I3NPASM	0.5° × 0.625° × 42 levels × 3 h	Gelaro et al., J. Climate, 2017	

3. SF Concept

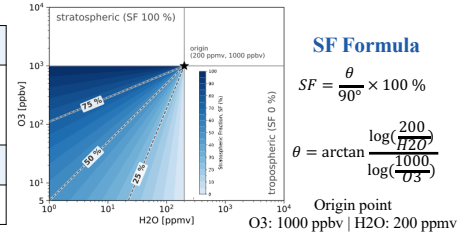


Fig. 1. Schematic of the stratospheric fraction (SF) in O₃–H₂O tracer space. Shading indicates SF (%); dashed lines mark the 25, 50, and 75% isolines, and the star marks the origin (200 ppmv, 1000 ppbv).

4. Daily Ozonesonde Campaign at Anmyeon (Pre-ACCLIP, Aug 2021)

Daily ozonesondes launched at Anmyeon captured a stratospheric ozone intrusion on 17–19 August 2021: the UTLS accounted for ~60% of the total-column ozone enhancement.

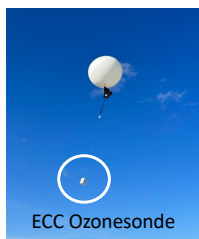


Fig. 2. Ozonesonde balloon launch.

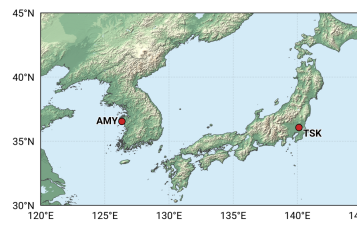


Fig. 3. Locations of the Anmyeon and Tsukuba sites.

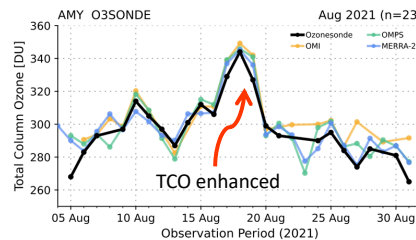
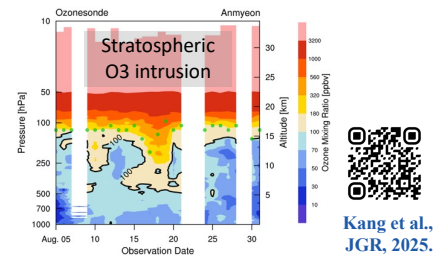


Fig. 4. Total column ozone (DU) at Anmyeon in August 2021 from ozonesondes (black), OMI (orange), and MERRA-2 (blue).



Kang et al., JGR, 2025.

5. Stratospheric Fraction at the Observation Sites

AMY Anmyeon, Korea

18 Aug 2021

TSK Tsukuba, Japan

19 Apr 2017

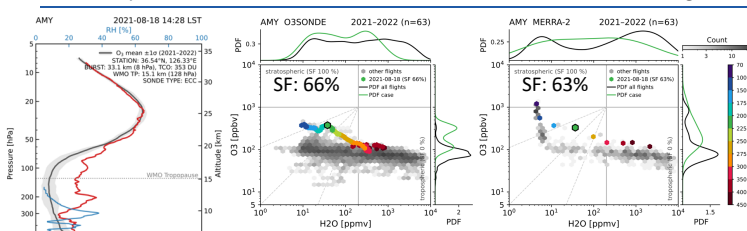
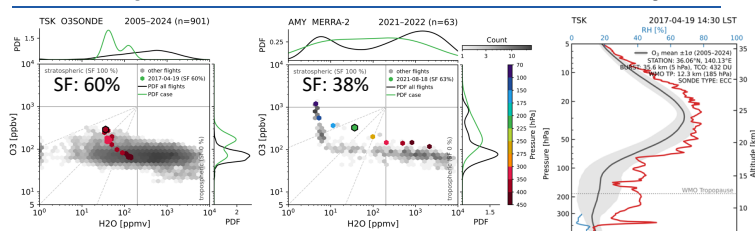


Fig. 7. O₃–H₂O relationship at Anmyeon between 450 and 70 hPa from (left) ozonesondes and (right) MERRA-2, 2021–2022. Gray shading: data density of all other flights; colored markers: the 18 August 2021 case, colored by pressure, with the ozone-peak level outlined in black. Marginal panels show PDFs for all flights (black) and the case (green).



(Above) Fig. 11. As in Fig. 7, but for Tsukuba, 2005–2024, with the 19 April 2017 case highlighted.

(Right) Fig. 10. As in Fig. 6, but for Tsukuba on 19 April 2017 (14:30 LST); the site mean is for 2005–2024.

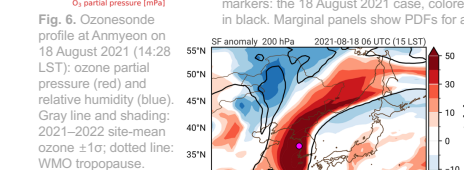


Fig. 8. Stratospheric fraction (SF) anomaly (%) at 200 hPa at 06 UTC 18 August 2021, relative to the 2005–2024 August climatology. Black contours: 2 PVU; magenta dot: Anmyeon observation site.

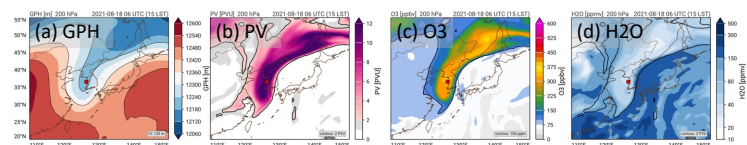


Fig. 9. Synoptic fields at 200 hPa at 06 UTC 18 August 2021: (a) geopotential height (m), (b) potential vorticity (PVU), (c) ozone (ppbv), and (d) water vapor (ppmv). Black contours: 2 PVU in (b) and (d), 100 ppbv in (c); red dot: Anmyeon.

- Both profiles show a sharp ozone increase below the tropopause, exceeding the site mean +1 σ , together with very low RH.
- SF from the O₃–H₂O relationship is 66% (AMY) and 60% (TSK) for the ozonesondes, versus 63% and 38% from MERRA-2.
- At the TSK ozone peak, MERRA-2 is both too moist and too ozone-poor, because both tracers are weakly constrained in the upper troposphere (Jiang et al., JGR, 2015; Wargan et al., JC, 2017).
- During STE events an upper-level trough or cut-off low is present, with high PV following its shape. Furthermore, ozone is high and water vapor is low, and is clearly positive.

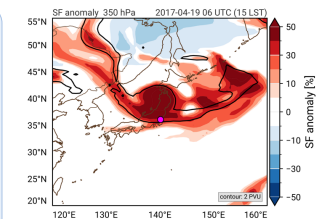


Fig. 12. As in Fig. 8, but at 350 hPa at 06 UTC 19 April 2017, relative to the 2005–2024 April climatology. Magenta dot: Tsukuba observation site.

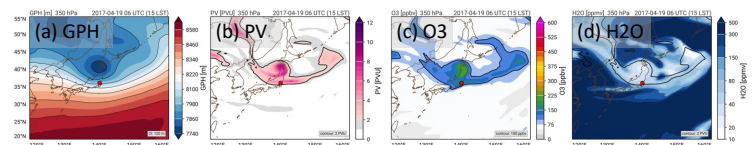


Fig. 13. As in Fig. 9, but at 350 hPa at 06 UTC 19 April 2017. Red dot: Tsukuba.

6. Conclusions

1. Daily ozonesondes launched at Anmyeon captured a stratospheric ozone intrusion on 17–19 August 2021: the UTLS (50–200 hPa) accounted for ~60% of the total-column ozone enhancement.
2. SF reaches 66% (AMY) and 60% (TSK) at the ozone peaks. MERRA-2 matches the deep AMY case (63%) but not the thin TSK layer (38%). In both cases, positive SF anomalies above +50% follow the high-PV trough.

7. Further Study

1. Blend ozonesonde humidity with other observation (e.g., IAGOS, MLS) to extend SF into the lower stratosphere, where radiosonde RH is unreliable.
2. Test what SF physically means with an idealized mixing experiment (does SF 50% mean half stratospheric air?), then extend from case studies to an SF climatology and classification of intrusion types.