**Table S1. Aerosol model comparison used in AOD/ALH retrievals for GEMS and TROPOMI/EPIC**

| | | GEMS | | | EPIC/TROPOMI | |
|---|---|---|---|---|---|---|
| | | HAF | Dust | NA | Dust | Smoke |
| mr | | 1.46 | 1.48 | 1.41 | $0.00428 \ln \tau + 1.55$ (675 nm) | $0.026\tau+1.513$ (680 nm) |
| mi | | 0.02044 | 0.00414 | 0.00401 | $0.00197 \ln \tau + 0.00268$ (675 nm) | 0.00857 (680 nm) |
| Reff | Fine mode | 0.0854 | 0.0644 | 0.1013 | $0.0152\tau+0.122$ | $0.017\tau+0.178$ |
| | Coarse mode | 1.4115 | 1.0392 | 0.8176 | - | $0.579\tau+2.477$ |
| Veff | Fine mode | 1.5421 | 1.4420 | 1.5870 | $0.156\tau+0.227$ | 1.26 |
| | Coarse mode | 1.7630 | 1.6436 | 1.9371 | - | 0.278 |
| fmf | | 0.99994 | 0.99823 | 0.99980 | $-0.0696 \ln \tau + 0.37$ | $0.162\tau+0.532$ |
| SSA | | Retrieved together with AOD from AERONET inversion dataset | | | Coarse mode: $0.0214 \ln \tau + 0.949$ (675 nm) | |
| Phase function | | Mie | | | Fine: Mie Coarse: Dynamic AERONET climatology | Mie |

$\tau$ is the AOD at 680 nm.
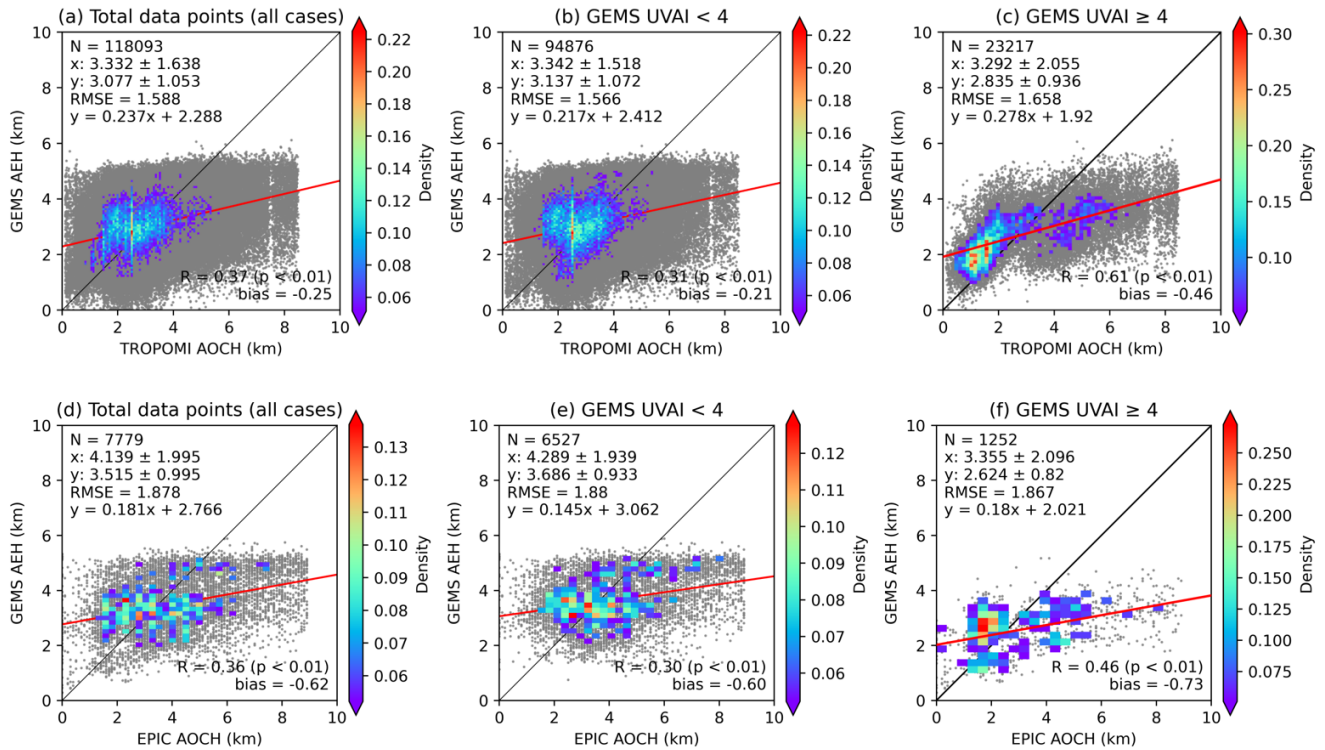
**Figure S1. Intercomparison of ALH products from GEMS, TROPOMI and EPIC for dust and smoke cases as a function of UVAI.** Density scatter plot of (a) GEMS and TROPOMI ALH comparison and (d) GEMS and EPIC ALH comparison for all dust cases. (b) and (c) are same as (a) but for GEMS UVAI < 4 and UVAI ≥ 4, respectively. (e) and (f) are same as (d) but for GEMS UVAI < 4 and UVAI ≥ 4, respectively. GEMS AEH converted into EPIC (or TROPOMI) AOCH definition.

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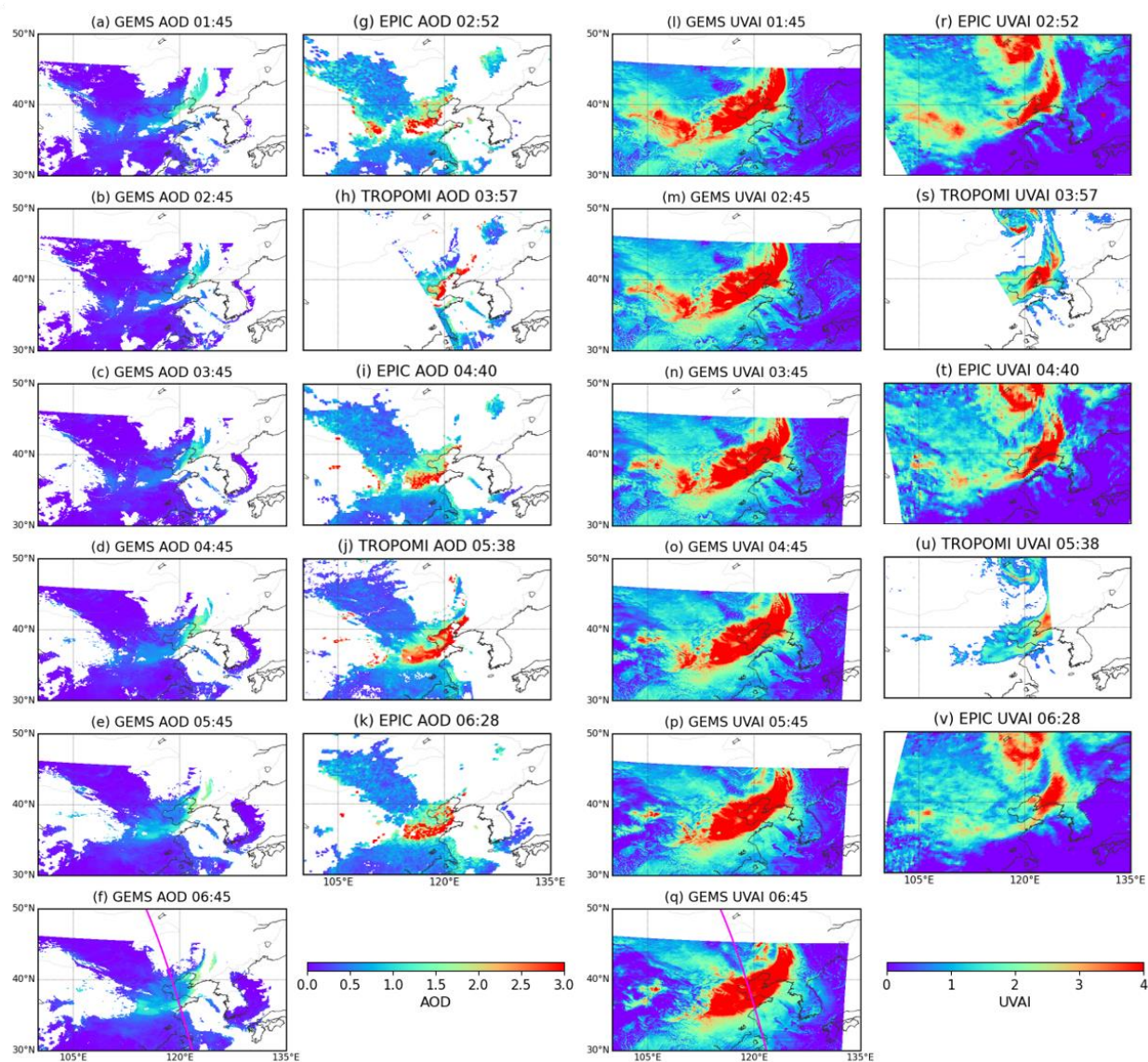


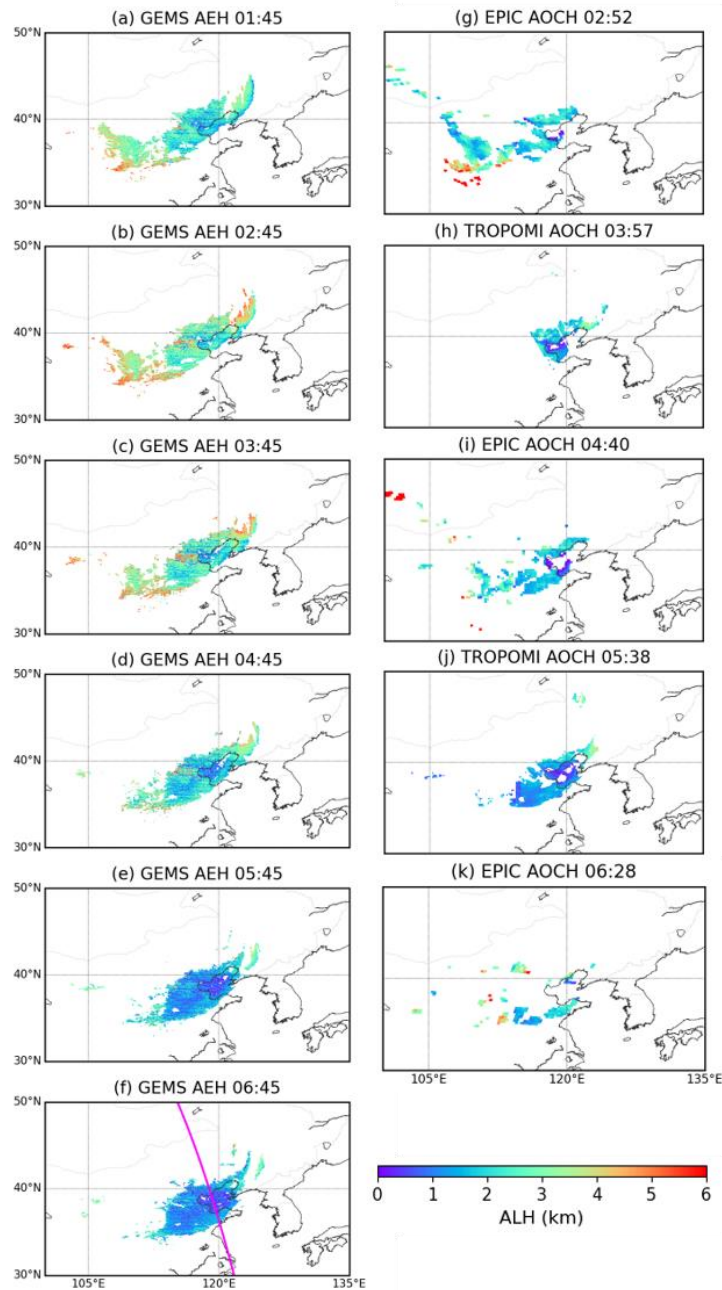
**Figure S2.** First column (a – f) shows hourly GEMS AOD products presented in timely order from (a) 01:45 to (f) 06:45 (UTC). Second column (g – k) EPIC and TROPOMI ALH aligned with the nearest time of GEMS measurement time for a dust plume case on 28 March 2021. Third column (l – q) shows GEMS UVAI and fourth column (r – v) shows EPIC and TROPOMI UVAI similar
15 to the first and second columns. CALIOP ground tracks are shown as magenta lines on the first and third columns where it has the closest observation time with GEMS.

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**Figure S3. Regional coverage for absorbing aerosols screened by UVAI thresholds as 3, 1, 2, for GEMS, TROPOMI, and EPIC, respectively. First column (a – f) shows hourly GEMS ALH products presented in timely order from (a) 01:45 to (f) 06:45 (UTC). Second column (g – k) EPIC and TROPOMI ALH aligned with the nearest time of GEMS measurement time for a dust plume case on 28 March 2021. CALIOP ground tracks are shown as the magenta line on the GEMS ALH map (first column) where it has the**
25 **closest observation time with GEMS.**
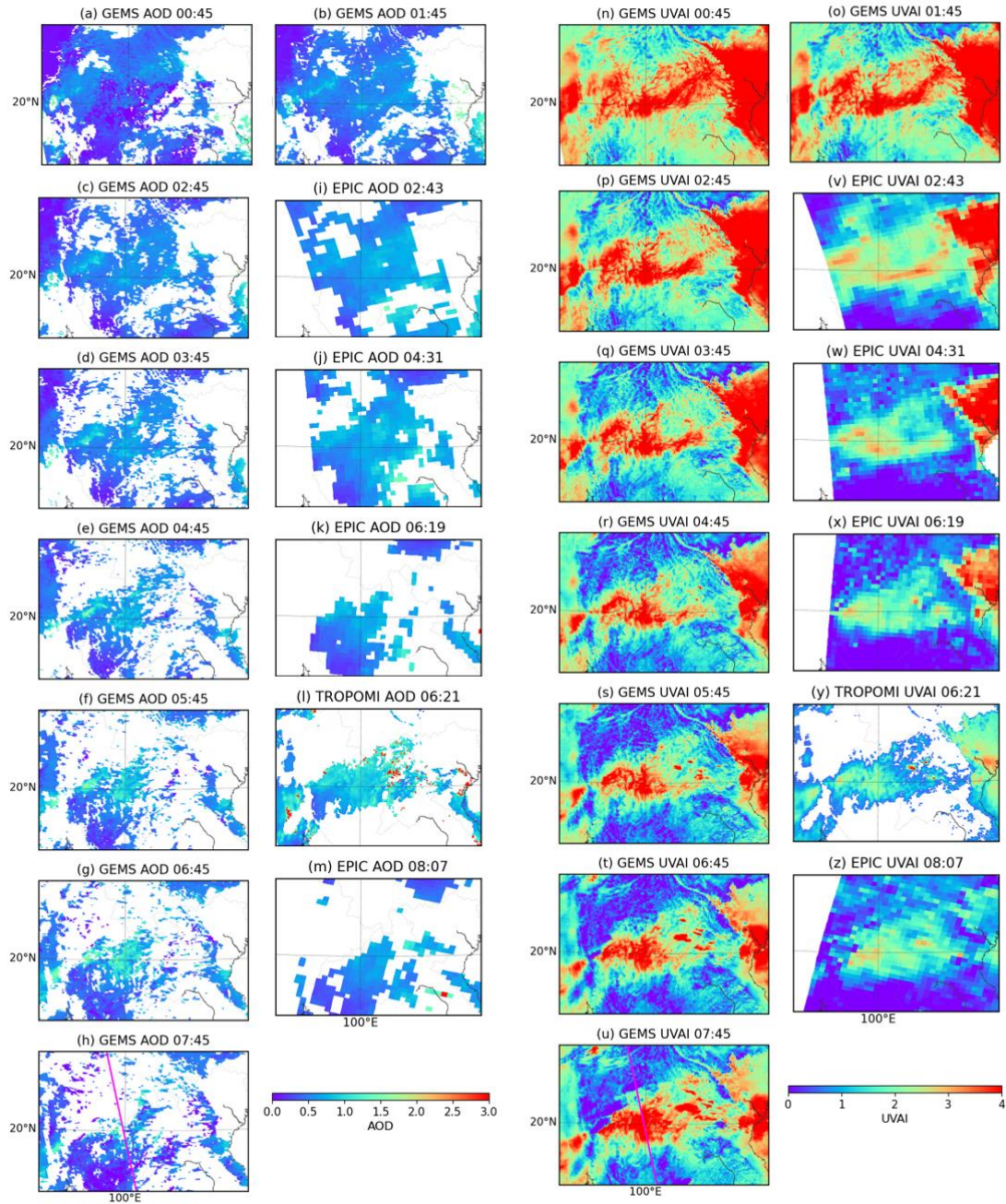
**Figure S4.** Figures a - h show hourly GEMS AOD products presented in timely order from (a) 00:45 to (f) 07:45 (UTC). Figures i - m EPIC and TROPOMI ALH aligned with the nearest time of GEMS measurement time for a dust plume case on 17 April 2023. Figures n - u show GEMS UVAI and Figures o - z show EPIC and TROPOMI UVAI similar to the AOD figures. CALIOP ground tracks are shown as magenta lines on the first and third columns where it has the closest observation time with GEMS.
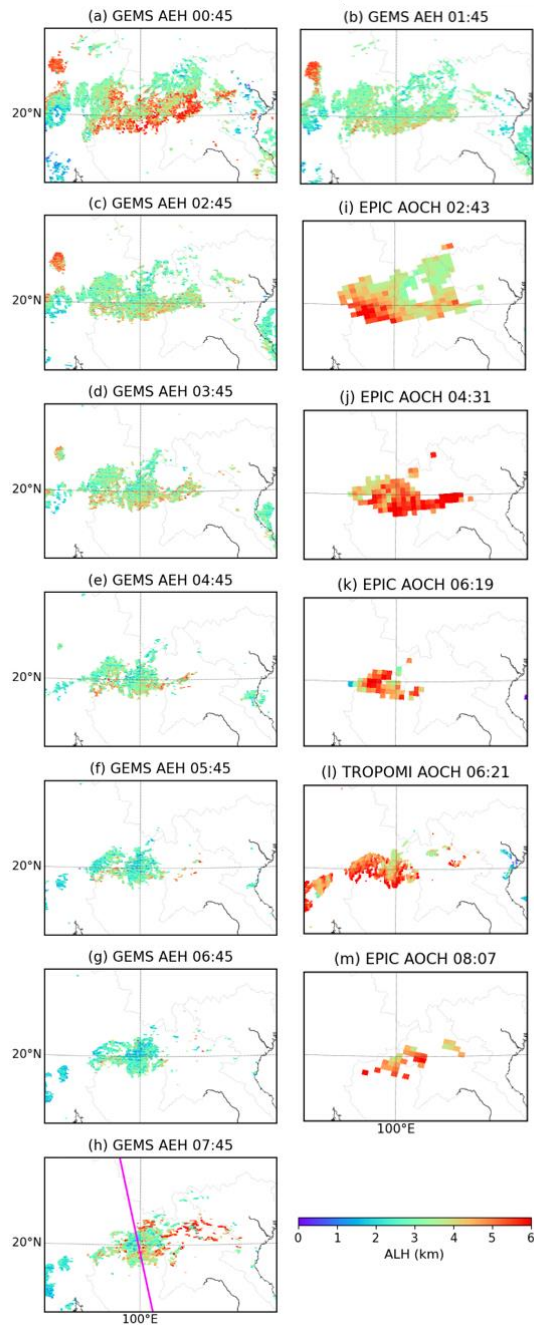
**Figure S5. Regional coverage for absorbing aerosols screened by UVAI thresholds as 3, 1.5, 2, for GEMS, TROPOMI, and EPIC, respectively. Figures a - h show hourly GEMS ALH products presented in timely order from (a) 00:45 to (f) 07:45 (UTC). Figures i - m show EPIC and TROPOMI ALH aligned with the nearest time of GEMS measurement time for a smoke plume case on 17 April 2021. CALIOP ground tracks are shown as the magenta line on the GEMS ALH map (first column) where it has the closest observation time with GEMS.**