Aerosol Direct Radiative Effect During Covid-19

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Aerosol Direct Radiative Effect

\[ ADRE = F(0, \alpha; x_1, x_2, \ldots, x_n) - F(\tau_a, \alpha; x_1, x_2, \ldots, x_n) \]

\[ F(0, \alpha; x_1, x_2, \ldots, x_n) = \text{Clear-sky SW TOA Flux with no aerosol} \]

\[ F(\tau_a, \alpha; x_1, x_2, \ldots, x_n) = \text{Clear-sky SW TOA Flux with aerosol} \]
Aerosol Direct Radiative Effect Anomaly

\[ \delta ADRE = \delta F(0, \alpha) - \delta F(\tau_a, \alpha) \]

\( \delta F(\tau_a, \alpha) \) can be decomposed into atmospheric and surface contributions using EBAF TOA and surface radiative fluxes:

\[ \delta F(\tau_a, \alpha) = \delta F(\text{ATM}) + \delta F(\text{SFC}) \]

- First term on RHS accounts for atmospheric variations for a fixed climatological surface albedo.
- Second term on RHS accounts for surface albedo variations, determined from difference between the other two terms.
Aerosol Direct Radiative Effect Anomaly

\[ \delta ADRE = -\delta F(\text{ATM}) + [\delta F(0, \alpha) - \delta F(SFC)] \]

- \(\delta F(\text{ATM})\) Determined from EBAF Ed4.1 product.
- \([\delta F(0, \alpha) - \delta F(SFC)]\) Determined from SYN1deg product.

Atmosphere-Only Variations

Masking effect of aerosols on surface albedo variations simply due to the presence of aerosols.
Observations

- CERES EBAF Ed4.1
- CERES SSF1deg-Aqua Ed4.0
- CERES SYN1deg-Terra_Aqua Ed4.0
- Nino 3.4 Index from NOAA ESRL
- MODIS MYD08_M3.061 550 nm AOD Dark Target+Deep Blue Combined
- MERRA-2 U2M, V2M, T2M, QV2M

Dates: 07/2002-03/2020
Surface Types: ocean, land and desert (no snow/sea-ice).
- Stippled area exceeds 95% confidence interval in trend.
- Significant increase in ADRE and decrease in AOD over China and east coast of North America. Decrease in ADRE and increase in AOD over India.
- AOD shows widespread significant increase over Ocean in Southern Hemisphere. Inconsistent with ADRE trend.
Trend in Zonal Mean Anomalies of SW Clear-Sky ADRE and AOD (2002/07-2020/03)

- Shaded regions correspond to 95% confidence interval.
Anomalies in ADRE and AOD for Global, Northern and Southern Hemispheres (07/2002—03/2020)

- No significant global trends

- ADRE: +ve trend in NH

- Surprising SH trend in AOD.
- Possible calibration drift in MODIS?
Slope: $-23.5 \pm 1.0 \text{ Wm}^{-2} \text{ per } \tau$
$R^2: 0.71$

Slope: $-24.1 \pm 0.81 \text{ Wm}^{-2} \text{ per } \tau$
$R^2: 0.81$

Slope: $-21.3 \pm 1.1 \text{ Wm}^{-2} \text{ per } \tau$
$R^2: 0.65$
Transportation and industrial activity during Covid-19 shutdown in China was at a minimum in February, yet ADRE anomalies over eastern China are much greater in March than February. Why?

In contrast, AOD anomalies are similar in February and March. Why?
Accounting for Regional Meteorological Variability

- Use multilinear regression model to relate anomalies in ADRE and AOD with anomalies in:
  
  i)  Niño 3.4 index (NOAA ESRL)
  
  ii) 2-meter eastward wind (U2M) (MERRA-2)
  
  iii) 2-meter northward wind (V2M) (MERRA-2)
  
  iv) Estimated Inversion Strength (EIS) (CERES SSF1deg)
  
  v) 2-m air temperature (T2M) (MERRA-2)
  
  vi) 2-m specific humidity (QV2M) (MERRA-2)
  
  vii) Daytime average cloud fraction between the surface and 700 mb (CERES SSF1deg)

Notes:
- All variables are detrended prior to determining multilinear regression fit
- Derive multilinear regression fit for 9°×9° latitude-longitude moving window (steps of 1°)
R-Squared values for multilinear regression fits to ADRE monthly anomalies (2003-2020)

- Explained variance ($R^2$) reaches 0.8 over Yellow Sea region.
- Low $R^2$ values over ocean away from coast.
ADRE Anomalies for Feb & Mar 2020: Accounting for Meteorology & Incoming Solar Flux
AOD Anomalies for Feb & Mar 2020: Accounting for Meteorology
Anomalies in T2M and QV2M and Contributions to ADRE Anomalies (February 2020)
Anthropogenic Emissions of $\text{SO}_2$ (including biofuels) for March 2005

Domain: 30°-45°N, 115°-130°E
Monthly Anomalies in ADRE over China (30°-45°N, 115°-130°E)

- Positive ADRE long-term trend due mainly to pollution controls
- Corresponds to 1.8 Wm\(^{-2}\) over 17.7 years (13% increase in ADRE relative to the climatological average)

- Accounting for meteorology and solar flux reduces both long-term trend and variability.

- After accounting for meteorology, solar flux and removing long-term trend:
  - Feb & Mar 2020 are only two consecutive months whose anomalies exceed 95% confidence interval.
  - ADRE values for Feb and Mar 2020 are 17% larger than the corresponding ADRE climatological averages
Conclusions (1/2)

- We have introduced a new method for determining anomalies in ADRE from CERES EBAF Ed4.1 and SYN1deg data.
  
  - Monthly anomalies in ADRE are consistent with MODIS AOD anomalies ($R^2=0.8$ for NH).
  - Pattern of regional ADRE trends resemble those for MODIS AOD, except over SH oceans.
  - Significant ADRE trend in NH due to pollution controls in China and USA.
  - No significant global trend in ADRE or AOD.
Conclusions (2/2)

- Meteorology played a significant role in explaining the lack of a strong signal in ADRE and AOD in February 2020, when the economic activity in China was at its minimum.
  
  • ADRE anomalies in March 2020 exceeded those in February 2020 over eastern China.
  
  • When adjusting for meteorology and incoming solar flux, anomalies in February dramatically increase.
  
  • T2M and QV2M are the largest contributors to ADRE in Feb 2020.
  
  • After accounting for meteorology and solar flux, February and March 2020 are the only two consecutive months in the CERES record to exceed the 95% significance level, even after long-term trend is removed.

=> Anomalous meteorological conditions masked the full impact of the Covid-19 shutdown on clear-sky SW TOA radiation over eastern China.