Impacts of South African Wildfire Aerosols on Stratocumulus over Southeast Atlantic Ocean

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Outline

- Motivation
- Model and observation data
- Evaluation of modeled wildfire aerosols and clouds
- Effects of wildfire aerosols on stratocumulus clouds
- Summary
2013 monthly active fire detections

2013 MODIS Active Fire Detections from the Aqua and Terra satellites

Active fires, shown in red, are detected using MODIS data from the Aqua and Terra satellites.
Motivation

- Wildfires in Southern Africa contribute ~27% of global wildfire aerosol emissions\(^1\)
- Wildfire season (July-August-September) in Southern Africa\(^2\) in coincidence with maximum *stratocumulus* season (August-September-October)\(^3\)

1. Van der Werf et al., 2010; 2. Randerson et al., 2012; 3. Wood, 2012
Motivation

► Smoke as **SW absorber** in S. Africa
  - **Direct effect**: smoke layer above clouds: negative RF $\Rightarrow$ positive RF depending on cloud fraction (Chand et al. 2009)
  - **Semi-direct effect**: smoke strengthens cloud-capping temperature inversion $\Rightarrow$ thicken stratocumulus clouds (Sakaeda, Wood, and Rasch 2011; Wilcox 2012)

► Smoke as **CCN** in S. Africa
  - **Indirect effect**: Less studied, especially for the nighttime period
  - During daytime, 56% of smoke layers elevated above clouds; 44% touching clouds based on Calipso observations (Constantino and Bréon 2013)
Motivation

- Modeling stratocumulus
  - Cloud radiative forcing underestimated by GCMs (IPCC AR5)
  - Organizational complexity: open/close cell
  - Coupling-decoupling cycle: shallow well-mixed STBL (night) ➔ a deep and decoupled STBL ➔ a cumulus-dominated boundary layer (daytime)

IPCC AR5

Coupling-decoupling of stratocumulus
Wood, 2013
Outline

✧ Motivation
✧ **Model and observation data**
✧ Evaluation of modeled wildfire aerosols and clouds
✧ Effects of wildfire aerosols on stratocumulus clouds
✧ Summary
Model and Data

- **WRF-Chem** model V3.6.1
- Domain and spatial resolution: 6000 km ($\Delta x=3$ km, E-W) $\times$ 1800 km ($\Delta y=3$ km, S-N) $\times$ 42 ($v$)
- Period: August 1 – October 31, 2014; 3-h output frequency
- Three cases: **SMOKE**, **CLEAN** (only sea salt and DMS-generated aerosols), and **NO_RAD** (radiative effect of smoke not considered)
- Aerosol-cloud-radiation interactions in WRF-Chem
  - MOSAIC aerosol scheme; Abdul-Razzak and Ghan cloud droplet activation parameterization
  - Cloud microphysics: Morrison two-moment scheme
  - Radiation: Goddard SW + RRTM LW schemes
- **Inner domain** simulation by **WRF** model: Domain size: 300km ($\Delta x=300$ m, E-W) $\times$ 300km ($\Delta y=300$ m, S-N) $\times$ 97 ($v$); $\Delta z=16$ m in 0~1 km, $\Delta z=32$ m in 1~2 km
Model and Data

- **Hourly smoke emissions**
  - The fire radiative power (FRP) technique\(^1\)
  - Smoke emission rate = FRP × \(C_e\) (\(C_e=0.021\) kg/MW)
  - FRP values from SERVIR satellite (resolution: 15 min + 3 km)
  - OC, BC mass ratios: Vegetation-dependent\(^2\); MODIS Land Cover Type (16 types)

### Table

<table>
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<tr>
<th>LCT Classification</th>
<th>Generic Vegetation Type</th>
<th>CO(_2)</th>
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<th>H(_2)</th>
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Modeled above-cloud smoke AOD is compared against above-cloud MODIS AOD from Meyer et al. (2015).

Model vs. MODIS AOD averaged over Aug. and Sept. 2014: 0.351 vs. 0.354; Pattern well simulated.
Evaluation – modeled cloud fraction

- Model reasonably reproduces cloud patterns.
- Model successfully captures the regions, which experience the largest cloud fraction variation from morning to afternoon/noon.

Averaged cloud retrieval fraction_liquid by Terra and Aqua Level 3, Aug.~Sept. 2014

Averaged cloud fraction modeled by SMOKE case, Aug.~Sept. 2014

Terra 10:30 LST

Aqua 13:30 LST

SMOKE (09+12UTC)/2

SMOKE (12+15UTC)/2
Model fairly reproduces observed cloud liquid water path (LWP).

LWP: overestimated by ~20 g/m² over region 1; underestimated by ~20 g/m² over region 2

Model successfully captures the rapid decreases in liquid water path from morning to afternoon.
• Cloud top height gradually increases as clouds locate further away from the coast
• Cloud top are higher during the fire season (August) compared to non-fire season (November)
  – Meteorological condition
  – Smoke increases LWP \(\Rightarrow\) stronger entrainment at cloud top \(\Rightarrow\) higher cloud top
Evaluation – cloud top height

Averaged vertical distribution of layer AOD normalized by column AOD (noon, Aug.~Sept. 2014)

- From coast to remote regions
  - The cloud top height increases (avg. cloud m.m.r. > 0.001 g/kg)
  - The altitude of smoke plume decreases because of gravitational settling
  - More fraction of smoke is in touch with clouds
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The cloud tops in SMOKE are higher than CLEAN, indicating stronger entrainment rate.
Smoke effect on cloud LWP

Diurnal cycle of cloud LWP averaged over ocean modeled by the SMOKE and CLEAN cases, Aug.~Sept. 2014

- Cloud LWP diurnal cycle: Highest at 6 UTC (~ 6 LST); Lowest at 15 UTC
- SMOKE vs. CLEAN: Increase in LWP because of smoke indirect effect
Smoke effect on cloud fraction

Diurnal cycle of cloud fraction averaged over ocean modeled by the SMOKE and CLEAN cases, Aug.~Sept. 2014

* Cloud fraction diurnal cycle: Highest at 6 UTC (~6 LST); Lowest at 15 UTC
* SMOKE vs. CLEAN: increase at night because of smoke indirect effect, and decrease at daytime due to enhanced entrainment rates and a quicker decoupling caused by higher LWP
Smoke effect on cloud fraction

ΔCF between SMOKE and NO_RAD, Aug.~Sept. 2014

Near the coast: the radiative effect can increase CF by 1%, comparable to other modeling studies, e.g. 1~2% in Sakaeda et al., 2011.
Remote region: slightly decrease CF, probably due to large fraction of smoke in touch with clouds.
Summary

- We investigate the impact of wildfire aerosols from Southern Africa on stratocumulus over Southeastern Atlantic Ocean using the WRF-Chem model.
- Smoke plumes and cloud fields are reasonably well simulated.
- Smoke causes positive changes in LWP and cloud fraction during the night and early morning (due to the indirect effect); however, higher LWP leads to a quicker decoupling process (due to a stronger entrainment process) at daytime; the radiative effect of smoke can mitigate or slow down the decoupling process near the coast.