Transpacific transport of mineral dust: impact on aerosol in the United States

- Mobilization
- Long-range transport/Chemical transformation
- Deposition
Dust is a principal component of atmospheric aerosol

MODIS V3 AOD
From Chu et al., 2003
China dust storm, April 2001
SeaWifs

Beijing, March 29, 2004
Human Health

Visibility

Page, AZ, April, 2001

Public Safety

Riyadh, March, 2009
Helene’s Interaction with the SAL

Helene became a tropical depression on September 12th 2006. Its path led it directly into the SAL. Its developments appears to be inhibited by the SAL for it was only able to develop an eye after it cleared the SAL on September 18th. Helene went on to became a hurricane and eventually dissipated September 24th.

SAL METEOSAT product:

Courtesy:
UW-CIMSS/NOAA HRD
Dust can impact cloud droplet size, precipitation

AVHRR (false color) 3.7 \( \mu m \)
March, 1998
(from Rosenfeld et al., 2001)

Dusty (yellow-ish) clouds distinguished by \( R_{\text{eff}} < 14 \, \mu m \), below threshold for precipitation
**EPA Regional Haze Rule**

(i) “Natural visibility conditions” to be achieved by 2064 in federal class I areas; (ii) States to produce SIPs to reach those “natural visibility” goals; (iii) EPA provides default estimates of “natural concentrations” to define goals; (iv) States can propose refined estimates.

1. What effect does transpacific transport of mineral dust have on aerosol concentrations in the United States?
2. Does the impact extend beyond exceptional springtime episodes?
3. What are the implications for the EPA’s Regional Haze Rule?
1. Develop the mineral dust module for the GEOS-Chem global chemical transport model (CTM), (as part of a full suite of aerosol components).

2. Conduct global dust simulations; distinguish domestic from overseas contributions; use ground-based and airborne observations to interpret the model results.
GEOS-Chem is a global Chemical Transport Model (CTM); represents the sources, physical and photochemical processes that control the chemical composition of the troposphere.

The dust module represents the **mobilization**, **transport**, and **deposition** of mineral dust in the atmosphere.

- Four size bins: 0.1-1.0, 1.0-1.8, 1.8-3.0, 3.0-6.0 µm radius (following Ginoux et al., 2001)

- **Mobilization** -- GOCART (Ginoux) and DEAD (Zender) schemes available
- **Dry deposition** – gravitational settling, turbulent transfer, impaction, interception, \( V_d = V_d(D, \rho, sfc) \) (Zhang et al. 2001)
- **Wet deposition** – scavenging in convective updrafts; rainout and washout from large-scale and convective precipitation (Liu et al., 2001).
Dust mobilized indirectly by “saltating” sand particles.

Mobilization inhibited by soil moisture, non-erodible elements, snow cover, vegetation. (cartoon from Pye et al., 1987)

Define friction velocity, $U^*$

$$U^* = \sqrt{\frac{\tau}{\rho}}$$
Dust mobilization

Vertical dust flux, $F_d$, directly related to the horizontal saltation flux, $Q_s$, i.e., $F_d \sim S \cdot Q_s$

$$Q_s \sim U^*^3 \left(1 - \frac{U^*}{U^*_t}\right)\left(1 + \frac{U^*}{U^*_t}\right)^2$$  DEAD model

$$Q_s = U_{10}^2 (U_{10} - U^*_t)$$  GOCART model

$S$ – **source function** (defines potential dust source regions, includes vegetation, efficiency factors, e.g. topographic lows)

$U^*_t$ – **threshold friction velocity** (particle size, density, modulated by surface moisture)

Essential difference, GOCART vs. DEAD, is in defining $S$. DEAD lets **seasonal vegetation cover** control dust emission. GOCART restricts emission to **permanent arid regions**.
Globally, emissions distributions look similar, but large regional differences. For North America, GOCART emissions restricted to arid west; DEAD emissions found in northern plains from seasonal changes in vegetation.
Transpacific transport, April, 2001

Dust storm Gobi Desert

SeaWifs,
7 April 2001

Dusty air

SeaWifs,
11 April 2001

Clean air
GEOS-Chem Fine Dust Column, and mixing ratio
April 16, 2001

Source region (inner Asia)
Asian plumes over Pacific
Subsidence over western U.S.

700 hPa

mg m\(^{-2}\)

\(\mu g \ kg^{-1}\)
Asian dust observed at IMPROVE sites, April 2001

IMPROVE aerosol network: sulfate, nitrate, ammonium, elemental carbon (EC), organic carbon (OC), fine and coarse dust, sea salt.

Fine dust (PM2.5) = 2.2*Al+2.49*Si+1.63*Ca +2.42*Fe+1.94*Ti (Malm et al., 1994)
Asian Dust Event in Western U.S., April 16, 2001

**Simulated Asian dust**

*Great Basin*

**GRBA1 Fine Dust (PM2.5) Mass**

- IMPROVE: Great Basin, UT
- Model
- EPA default

Note persistence of simulated Asian dust enhancement

GOCART scheme
Annual mean (2001) fine dust at IMPROVE sites
Annual mean (2001) fine dust at IMPROVE sites

“Combined” uses GOCART source function with DEAD formulation
GEOS-Chem dust simulation for 2001

Source regions:
- East, Central Asia
- North Africa
- Middle East

Transport pathways:
- Transpacific
- Transatlantic
Comparison with U. Miami bulk aerosol climatology (Prospero and Savoie)

Model captures much of the magnitude and seasonal dust cycle over North Pacific. (note: different y-scales)
Monthly dust emissions and columns during TRACE-P (March) and ACE-Asia (April) field campaigns, 2001.

Model captures strong dust mobilization in East Asia, and outflow to the Pacific during TRACE-P and ACE-Asia.
Model comparison with TRACE-P and ACE-Asia obs.

Model generally unbiased in the free troposphere for TRACE-P; up to 70% low for ACE-Asia, when dust is 10 times as intense.
Seasonal comparison with IMPROVE fine dust

Model captures springtime nationwide peak in transpacific dust influence, mean (1.2 μg m⁻³ in west)
Domestic dust activity peaks in summer, due to meso-scale structures, e.g. dry convection, which the model underestimates.
Seasonal comparison with IMPROVE fine dust

Model indicates small but persistent (0.2-0.4 $\mu g \text{ m}^{-3}$) Asian dust presence in summer and fall (cf. EPA default for RHR 0.5 $\mu g \text{ m}^{-3}$)
The 20% worst visibility days in 2001: model vs. observed: and the contribution of dust

Dust contributes <10% in E, up to 50% in W to aerosol extinction. The model captures ~50% of the worst visibility days due to dust.
Simulated transpacific contribution to dust extinction on **worst dust days**, and number of worst dust days due to transpacific sources.

Transpacific sources contribute up to 100% to dust extinction in NW on worst dust days, and account for ~40% of worst dust days in the west. **States should account for Asian dust in setting realistic goals for regional haze.**
Principal findings

1. We find that Asian dust influence in the United States extends beyond springtime episodes. We attribute 0.12 (DJF), 1.2 (MAM), 0.25 (JJA), 0.25 (SON) $\mu g \text{ m}^{-3}$ to Asian fine dust in the west (30-50% lower in the east).

2. We attribute ~40% of the worst dust days in 2001 to transpacific sources.

3. We conclude that states should account for Asian dust in setting attainable goals for regional haze.
1. The impact of transpacific transport of mineral dust in the United States

2. The impact of mineral dust on nitrate, sulfate, and ozone in transpacific pollution plumes
Questions
Tropical Storm Development: Saharan Air Layer

WRF simulation of SAL shows enhancement of trade wind inversion, warming, moistening, and self-lofting of the dust layer.

(gray line is with, black line is w/o radiative feedbacks from dust)
(from Chen et al., JGR, 2010)
Saharan Air Layer (SAL) 20 July 2005

700 mb Temperature (AIRS, Aqua)  
**Warm**

700 mb Total Precipitable Water (AIRS, Aqua)  
**Dry**

Aerosol Optical Depth (AOD) (MODIS, Aqua)  
**Dust-laden**

(from Chen et al., JGR, 2010)
East Asian dust source regions

Yumimoto et al., 2009
Monthly Asian fine dust frequency at

From van Curen and Cahill (2002)
CALIOP 532 nm attenuated backscatter, with back trajectories, shows vertical structure in trans-Atlantic transport.

MODIS Aqua AOD shows dust outflow from N. Africa in August 2006.

Top-right figure by Kurt Severance, NASA. Figs. are from Zhaoyan. Liu et al., JGR, 2008.
Optical depth
550 nm

Optical Depth (Absorption)
550 nm

Single scattering Albedo
550 nm