How good are our GCM treatments of aerosol transport and wet removal?

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Wet deposition depends on-

- Interaction between aerosols, cloud microphysics, and cloud macrophysics (sub-grid distribution of cloud areas and properties)
- Concentration of aerosols, which depends on transport, emissions, wet and dry removal
Outline

• Approaches to wet deposition in GCMs and global transport models
• Sensitivity of aerosol distributions to wet deposition
• Sensitivity of tracer distributions to convective transports
• Fundamental cloud-aerosol parameterization issues
Parameterizations of Interactions between Aerosols and Cloud Microphysics/Macrophysics

- Recognize that precipitation occurs over fraction of large-scale grid box
- Limited treatment of gas/liquid (Henry’s Law) and aerosol/liquid (scavenging efficiency) interactions
Precipitating Fraction Parameterizations, I

- Cooke et al. (2002, JGR)
- Characterize aerosol as hydrophobic or hydrophilic based on emissions inventory and age
- Remove all hydrophilic aerosol in precipitating fraction $F = R/L$, where $R$ is rain path and $L$ is liquid path
Parameterizing Precipitating Fraction, II

- Liu et al. (2001, JGR)
Scavenging in Convective Updrafts

Fraction $adz$ of aerosols lost as air is lifted $dz$, scavenging efficiency $a$.

For hydrophilic aerosol, $a = C_1 / w$

$w$ is in-cloud vertical velocity and $C_1$ is rate of autoconversion of cloud liquid to rain.

Note that $w$ is not available in mass-flux cumulus parameterizations used in major GCMs.
Precipitating Fraction for Stratiform and Convective Clouds (Liu, 2001, *JGR*)

- Stratiform: $F = \frac{F_0 R}{L C_1}$
- Convective: $F = \frac{F_0 R}{(L C_1 F_0 + R)}$
- $F_0$ is large for stratiform and small for convective
- Used for rainout (in clouds for temperatures greater than 258K with riming) and for washout below clouds (factored with proportion of precipitation)
Cirrus Precipitation

- Stratiform clouds at pressures less than 400 hPa are cirrus
- Empirical relationship relates ice content to temperature
- Empirical relationship relates settling rate of ice to ice content
Gas/Liquid and Aerosol/Liquid Interactions in MOZART

- Horowitz et al., 2003, *JGR*
- Gases: Use liquid content and Henry’s Law, along with a scavenging efficiency
- Aerosols: Scale (depending on hygroscopic properties) relative to nitric acid
What is the impact of uncertainties in wet deposition on aerosol distributions?
Ratio of column burdens for half wet deposition

from Cooke et al. (2002, JGR)
from Cooke et al. (2002, JGR)
from Cooke et al. (2002, JGR)
from Cooke et al. (JGR, 2003)
What roles do key physical processes play in wet deposition?
from Liu et al. (2001, JGR)
Figure 10. Comparison between simulated (dotted line) and observed (solid line) vertical distributions of (left) $^{210}$Pb and (right) $^7$Be during PEM-West B for the three regions of Figure 9: remote Pacific (R1) and near Asia (NA1 and NA2). Dot-dot-dashed lines show model results for a simulation where the stratospheric $^7$Be source is shut off. Long-dashed lines show model results for a simulation where aerosol scavenging by cirrus precipitation (section 2-d) is included. Individual aircraft measurements are shown as dots and the corresponding 1-hm averages are shown as crosses. Note the larger scale for $^7$Be at NA2. See text for details.
Dash: Cirrus
Long Dash: No Cirr

from Liu
et al. (2001, JGR)

Central Pacific
Low Latitude

Central Pacific
Middle Latitude

East Pacific

Figure 11. Comparison between simulated (dotted line) and observed (solid line) vertical distribution of (left) \(^{210}\text{Pb}\) and (right) \(^{7}\text{Be}\) during PUM-Tropics A over the six regions of Figure 9: western Pacific low latitude (WP LL1 and WP LL2), western Pacific middle latitude (WP ML), central Pacific low latitude (CP LL1), central Pacific middle latitude (CP ML), and eastern Pacific (EP). Dotted-dashed lines are for a simulation where stratospheric \(^{7}\text{Be}\) source is shut off. Long-dashed lines are for a simulation where cirrus precipitation (section 2.4) is excluded. Individual aircraft measurements are shown as dots and the corresponding 1-km averages are shown as crosses. See text for details.
Solid-Obs; Circles-Climo Obs; Dotted Line-No Rimming below 258K; Dash-Dot Line-Rimming below 258K

from Liu et al. (2003, JGR)
Solid-Obs; Circles-Climo Obs; Dotted Line-No Riming Below 258 K; Dash-Dot Line: Riming below 258 K

from Liu (2001, JGR)
Large uncertainties in tracer distribution arise from the treatment of cumulus convection in GCMs
Wet deposition parameterizations depend on-

- Concentration of aerosols
- Distribution of intensity of precipitation
- Ice content in cirrus
- Stratiform vs convective precipitation
- Vertical velocities in clouds
- Liquid content
- Precipitating fraction
How well do GCMs represent the fields on which wet deposition depends?
Intensity Distribution of Precipitation Events

Black: SSMI
Red: RAS
Green: Donner
Stratiform vs. Convective Fraction
Averages For CAPE between 1500 and 3000 J kg\(^{-1}\); Land, Ocean within 4 J kg\(^{-1}\)

From Donner et al. (2001, J. Climate)
from Donner et al. (2001, J. Clim.)
Problems with precipitating fraction approach to removal:

• Precipitating fraction parameterizations do not depend on intensity of precipitation, only precipitation/liquid ratio
• Tuning parameters with limited physical meaning
• Not consistent with cloud and precipitation formation processes
• Prognostic aerosols should interface with microphysics directly
from Wilcoxon and Ramanathan (2004, *Tellus*)
Summary

• Aerosol simulations in GCM exhibit some success, but-
• Wet deposition parameterizations not linked physically to microphysics
• Wet deposition parameterizations depend strongly on aspects of GCM cloud parameterizations which require substantial further development
• Tracer transport, esp. by convection, uncertain