Clouds and Fogs in the Earth system

Pierre Herckes
Cloud chemistry
Why do we care about clouds?
7-15% contains clouds but aq phase $10^{-7}$ vol/vol

Up to 50% surface

NASA.gov
Fogs – “clouds that touch the ground”

Profound impact on air pollution episodes

London 1952: ~10,000 deaths…
Today… Paris, Beijing,…..
The life of a cloud droplet

Dry particle

Cloud droplet

Wet "haze" particle
The life of a cloud droplet

Wet "haze" aerosol

Dry particle

Cloud droplet

~ 10 minutes

~ weeks - months

~15 % rain out
Rain drop ~ 2 mm
Cloud drop ~ 0.02 mm
Condensation nucleus ~ 0.0002 mm
Hair ~ 0.1 mm
Liquid Water Content
LWC 0.02-0.5 g/m³
10s ~ 100 droplets/cm³

Strasbourg (France)

LWC 0.05-3 g/m³
~ 250 droplets/cm³

Flagstaff, AZ
How study fogs and clouds?
NCAR airborne cloudwater collector
Mt. Tai (China) cloudwater (Desyaterik et al., JGR, 2013)
Chemistry

H_{2}CO_{3} HCO_{3}^{-} CO_{3}^{2-} H^{+} H^{+}, RCOO^{-} H^{+}, RCOO^{-} H_{2}SO_{3} HSO_{3}^{-} SO_{3}^{2-} H^{+} RCOOH H_{2}O_{2}, O_{3} H_{2}O_{2}, O_{3} NH_{4}^{+}, OH^{-} NH_{3} HCl, HNO_{3} RNH_{3}^{+}, OH^{-} R-NH_{2} RCHO CH(OH)CH(OH) CHOCHO CHOCHO Hg NH_{4}^{+}, SO_{4}^{2-}, NO_{3}^{-} Ca^{2+}, Mg^{2+} Na^{+}, Cl^{-}, Metals, Organics NH_{4}^{+}, SO_{4}^{2-}, Metals, Organics

Small Particles

H_{2}O_{2}, O_{3}
What processes happen at the droplet scale?

“aqueous phase reactor”

gases

Reactions?

? 

? 

? 

"gases’"
What processes happen at the droplet scale?

- dry deposition
- occult deposition
- wet deposition
- precipitation
absence of precipitation
but
impaction of wind driven droplets onto surfaces/vegetation
Low hydrologic input (5%)

Substantial chemical deposition fluxes

Similar results for Alps, Sierra Nevada
Fog/cloud harvesting
How about clouds and climate?
<table>
<thead>
<tr>
<th>Emitted compound</th>
<th>Resulting atmospheric drivers</th>
<th>Radiative forcing by emissions and drivers</th>
<th>Level of confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>CO₂</td>
<td>1.68 [1.33 to 2.03]</td>
<td>VH</td>
</tr>
<tr>
<td>CH₄</td>
<td>CO₂, H₂O, O₃, CH₄</td>
<td>0.97 [0.74 to 1.20]</td>
<td>H</td>
</tr>
<tr>
<td>Halo-carbons</td>
<td>O₃, CFCs, HCFCs</td>
<td>0.18 [0.01 to 0.35]</td>
<td>H</td>
</tr>
<tr>
<td>N₂O</td>
<td>N₂O</td>
<td>0.17 [0.13 to 0.21]</td>
<td>VH</td>
</tr>
<tr>
<td>CO</td>
<td>CO₂, CH₄, O₂</td>
<td>0.23 [0.16 to 0.30]</td>
<td>M</td>
</tr>
<tr>
<td>NM VOC</td>
<td>CO₂, CH₄, O₃</td>
<td>0.10 [0.05 to 0.15]</td>
<td>M</td>
</tr>
<tr>
<td>NOₓ</td>
<td>Nitrate, CH₆, O₂</td>
<td>-0.15 [-0.34 to 0.03]</td>
<td>M</td>
</tr>
<tr>
<td>Aerosols and precursors</td>
<td>Mineral dust, Sulfate, Nitrate, Organic carbon, Black carbon</td>
<td>-0.27 [-0.77 to 0.23]</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>Cloud adjustments due to aerosols</td>
<td>-0.55 [-1.33 to -0.06]</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td>Albedo change due to land use</td>
<td>-0.15 [-0.25 to -0.05]</td>
<td>M</td>
</tr>
<tr>
<td>Natural</td>
<td>Changes in solar irradiance</td>
<td>0.05 [0.00 to 0.10]</td>
<td>M</td>
</tr>
</tbody>
</table>

Total anthropogenic RF relative to 1750:
- 2011: 2.29 [1.13 to 3.33] (H)
- 1980: 1.25 [0.64 to 1.86] (H)
- 1950: 0.57 [0.29 to 0.85] (M)
What processes happen at the droplet scale?

“aqueous phase reactor”

gases

Reactions?

?}

?}

?}

gases’

gases’

gases
What processes happen at the droplet scale?

“Black carbon (Soot)”

Lifetime depends if scavenged or not
Scavenging of soot (BC) in clouds

Substantial variability – how to include in models?
How about air quality?
Fogs/clouds clean?

gases

Reactions?

gases'

deposition
o.k. some chemistry.....

volatiles

Reactions?

Vol’

Volatiles’
Processing of PAH
Chrysene Oxidation Products

Higher solubility
Lower toxicity

(J. Eagar)
How about polluting?
Nitrosamines

Fresno (CA) 240 ppt
Selinsgrove (PA) 240-500 ppt
Mt. Elden (AZ) 210 ppt
EPA (drinking wat.) <7ppt

HONO (CH₃)₂NH
Production of solid material

Atmospheric models underestimate particulate matter
Whistler Aerosol and Cloud Study
Particulate organic matter production from gas phase precursors

Cloud formation possible
But slow and too little
New theory: haze droplets
Anthropogenic impact on fogs/clouds…

a positive story…
No more acid fogs
No more extreme concentrations
Life in the universe?
Life in clouds?
Organisms @ Genus level

- Massilia, 62.2%
- Rhizobium, 7.2%
- Pseudomonas, 3.4%
- Desulfomicrobium, 2.7%
- Herbaspirillum, 2.7%
- Dietzia, 2.1%
- Holdemania, 2.0%
- Propionibacterium, 1.8%
- Sporacetigenium, 1.4%
- Staphylococcus, 1.1%
- Duganella, 1.0%
- Ruminococcus, 1.6%
- Unclassified genus, 6.3%
- The others (<1%), 4.6%
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Same results than Puy de Dome (France) only other cloud study

Global atmospheric biome?
Funding for Cloud Chemistry Research

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Collaborations

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