Process-based emission inventories from the past to the future

Tami C. Bond
University of Illinois at Urbana-Champaign
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Biased toward: energy-related emissions, aerosols, climate, global
Outline

1. Process-based vs sectoral
2. Comments on the past and future
3. What to do with observations
4. Climate-relevant questions
1. PROCESS-BASED EMISSIONS
Two ways of estimating emissions

Process-based
Based on physical understanding of the underlying technologies and processes

Never fully realized!
Always some parameterization

Sector-based
Based on applying broad emission coefficients to large groups of sources ("sectors")
Two ways of estimating emissions

Process-based
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Sector-based
Based on applying broad emission coefficients to large groups of sources (“sectors”)

Measurement-based
Use measured emissions from individual facilities

Possible for large facilities & places with stringent environmental regulation
Example

this candle is making black carbon
right here

this one is making “organic” carbon…
no flame, no game!
Pros and cons

Process-based

Reflect physical reality
Includes “how-to” levers; demonstrate effect of individual actions

Data-intense
Difficult to validate each component

Sector-based

Fewer data needs
Capture broad trends and economy-wide policies

Big assumptions about emission trends without ability to investigate mechanism
Individual efforts can contribute:

- Emission factors: vetted with primary data sources; compared in different regions
- Emitter features that matter: e.g. vehicle age distributions
- Activity data that are not widely available

Quality control & data provenance are of paramount importance!
Need for community guidance

Especially beyond U.S./Europe

- Guidance on when emission factors are appropriate
- Guidance on transparency, data sources, and quality
- Identification of critical inventory needs

...some groups are starting to re-invent wheels
2. PAST & FUTURE
The evolution of combustion

- **Largely uncontrolled**
  - Coal
    - Largely uncontrolled turbulence, time in exhaust

- **Loosely managed**
  - Wood
    - Even more OC
    - Lots of VOC

- **Fuel-air managed**
  - Liquid
    - BC remains
    - OC + VOCs burned out
    - Hot!
    - More NOx

Physical result

- Lots of BC
- Even more OC
- Lots of VOC
Trajectory of anthropogenic aerosol emissions

...that is, not open biomass burning...

- Fire well-managed
  - High activity
  - End-of-pipe controls

- Fuel distilled
  - High emissions
  - Moderate activity
  - Transportation $\rightarrow$ BC, OC

- Fire manipulated
  - Moderate activity
  - Coal $\rightarrow$ SO$_2$, BC, OC, ash

- Fire Unmanaged
  - Low Activity
  - Wood $\rightarrow$ few impurities
  - Mainly OC + BC
From a process-based perspective...

present

is a lesson about the present

is a lesson about the past

is a lesson about the future
Better fuels

An oversimplified history of emissions
An oversimplified history of emissions

Better fuels

High EF
Low activity
Low capacity to mitigate

Moderate EF
Medium activity
Motivation to change

Low EF
High activity
Growing capacity to mitigate

Cleanest EF
High activity
Willingness to mitigate
“Bang-for-buck” decreasing

???
An oversimplified history of emissions

- Improved combustion
  - High EF
  - Medium activity
  - Low capacity to mitigate

- Optimized combustion
  - Lower EF
  - High activity
  - Growing capacity to mitigate

- End of pipe controls
  - Cleanest EF
  - High activity
  - Willingness to mitigate
  - "Bang-for-buck" decreasing

CRISIS

Better fuels

- Improved combustion
- Optimized combustion
- End of pipe controls
Questions about the future (mine)

- Will emissions rise again? (Minimum after the maximum)
- How strong is “leapfrogging”? 
- To what extent does capital stock and infrastructure lock in emission rates?
- How does regulation effectiveness depend on national priorities and governance?

my group has (lately) focused on connecting
On-road vehicle emission projections

Could increase or decrease, depending on economic trajectory

Yan et al., Atmos Env, 2011
Soon we will see whether we CAN minimize emissions with control technology

Yan et al., Atmos Env, 2011
Ideals for emission inventories:

- Seamless from past to future *
- Consistent among relevant pollutants **
- Rapidly updatable, based on technology stock and emission drivers *
- Each data point fully traceable to original source *
  - Emission factor, hierarchical activity, extrapolation
  - Includes uncertainty
- Linked to national circumstances, e.g. infrastructure, land use, regulation **
- Quality flags, including evaluation status
- Consistent among different inventory classes (e.g. biogenic & energy-related)

in my group:  * current practice; ** ongoing work
3. How I wish we could use Observations
A. Every observation comes with a label

1. Use tracer ratios, seasonality, and diurnal variability to apportion concentration totals among sectors
   - long-term observations with sufficient detail
   - ratios with CO$_2$ would be great
   - done now, but not systematically

2. Investigate causes of emission discrepancy

3. Propagate these findings to other regions and sectors

**PRODUCT OF A COMPRESSION-IGNITION ENGINE**

Greg’s “top-down”—NO$_2$ is best, particulate matter difficult

**GENERALIZE please**
B. We solve the resolution problem
(and the transport problem, too)

Especially for “peaky” primary aerosol distributions

Examples:
- Point observation doesn’t represent model boxes
  So tell me what it does represent!
- Urban-rural divide: trends & magnitudes

Need to formally and systematically disentangle these contributions
If I had that information....

I would fix the inventory throughout the past and future.

Emission factors are wrong.

Activity data are wrong.

We are missing a source.
If I had that information….

I would fix the inventory throughout the past and future.

Emission factors are wrong.

Activity data are wrong.

We are missing a source.

Or, the transport could just be messed up. Never mind.
4. Climate Questions

especially about aerosols
“How far back should we go?”

Answer: For what?

- Farther back = More uncertain (no activity records) and less constrained (no observations)
- Is an uncertain reference year useful in understanding climate forcing?

Also: How far forward should we go?
The aerosol-cloud connection

*Cloud-related forcing may be larger than direct forcing, and will (probably) die away more slowly*

- Need properties of aerosols relevant to clouds
  - Size—definitely; composition—possibly
- Need observations & constraints of cloud-relevant properties (if not cloud effects themselves)
  - And these must tie back to emissions
Needs:

- Community development of *lacking* (not repeated) data, and quality control
- Formalisms for learning from the past and understanding future
- Formalisms for assessing emissions vs observations given transport constraints
- Emission inventories for climate purposes, considering all limitations