Computational Challenges Posed by Simulating Complex Ecosystems and Large Numbers of Tracers in Earth System Models

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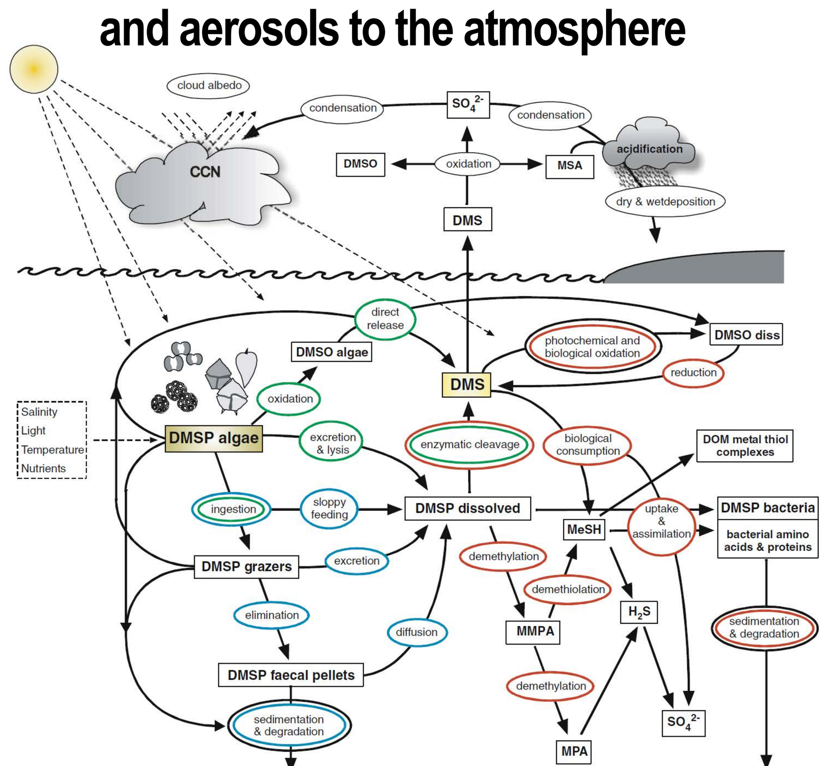
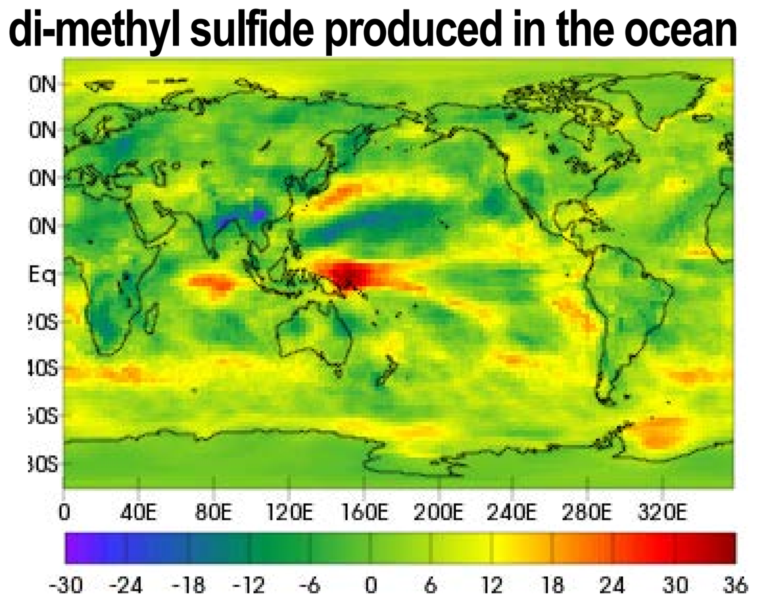
Biological emissions affect climate and air-quality

Ocean ecosystem is the source of many gases and aerosols to the atmosphere



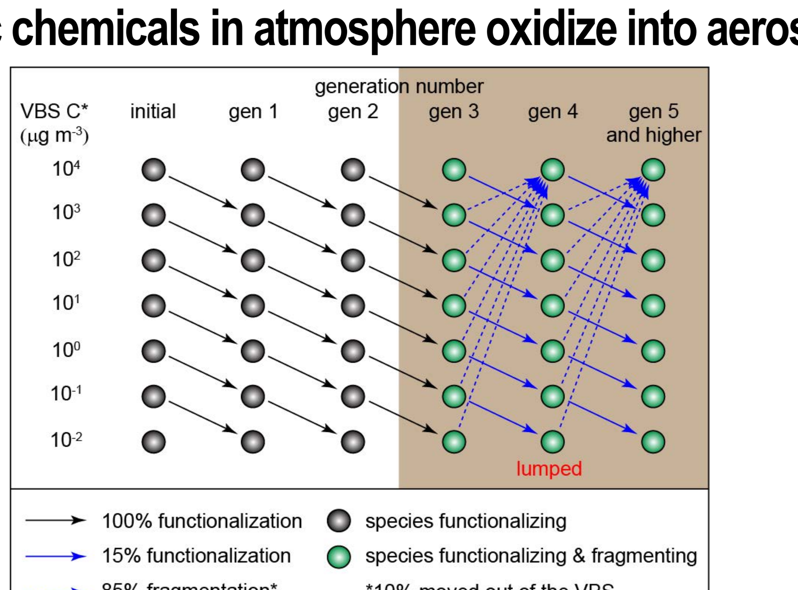
Stefels, et al. (2007)

Decrease in soar surface heating due to di-methyl sulfide produced in the ocean



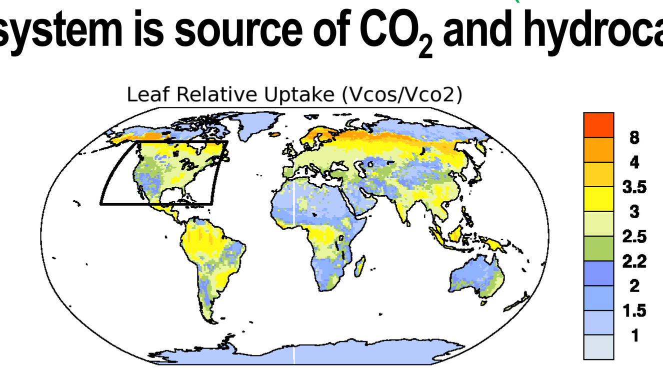
Global mean = 3.5 W/m^2 W/m^2

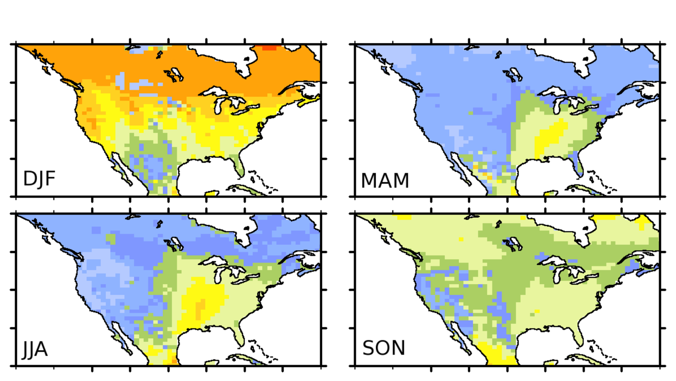
Organic chemicals in atmosphere oxidize into aerosols



Shrivastava, et al. (GRL, 2013)

Land ecosystem is source of CO_2 and hydrocarbons

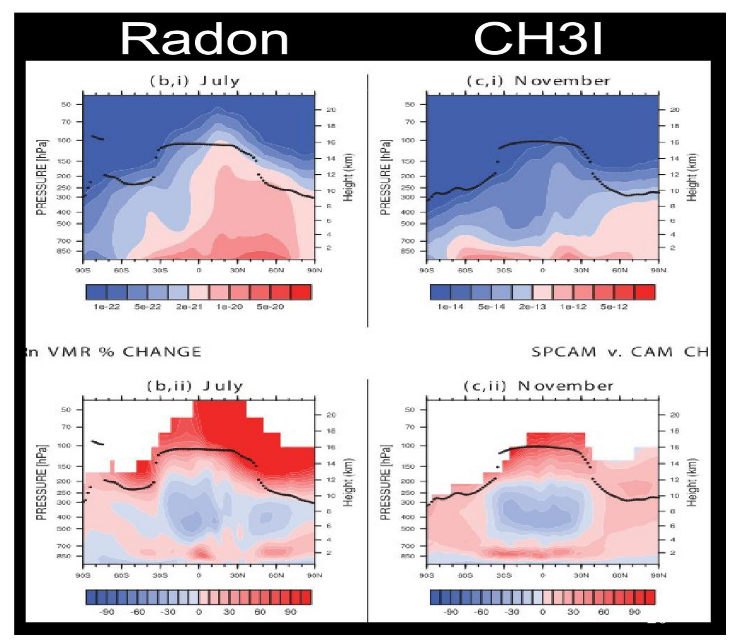




Carbonyl sulfide (OCS) is a natural tracer that is similar to CO2, and can be used to quantify the difference between photosynthesis and respiration.

Tracers can answer: who, what, where, why?

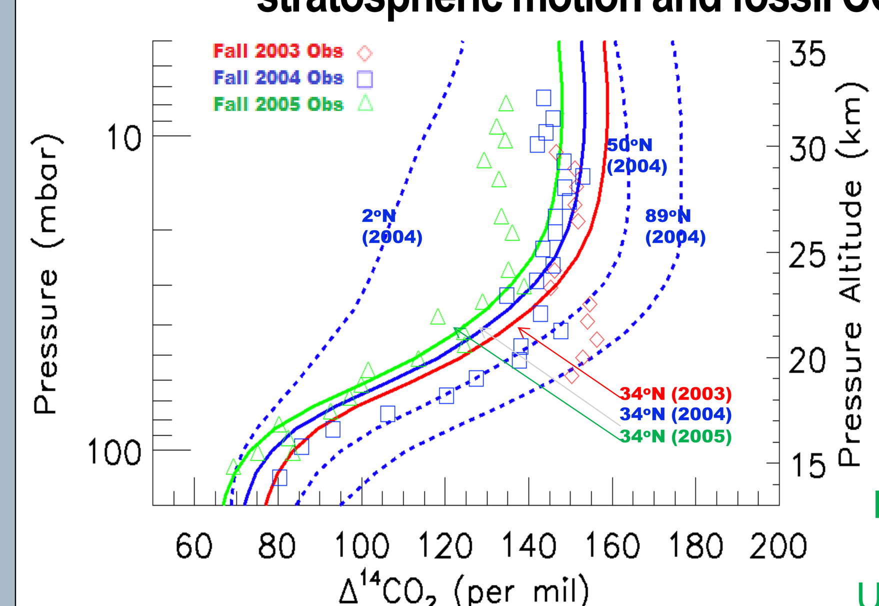
Natural tracers can validate unmeasurable processes



- ^{222}Radon affected by convective updrafts.
- CH_3I tracks uplift from oceans.
- SF_6 quantifies Interhemispheric exchange rate.

Rosa, et al. (2012)

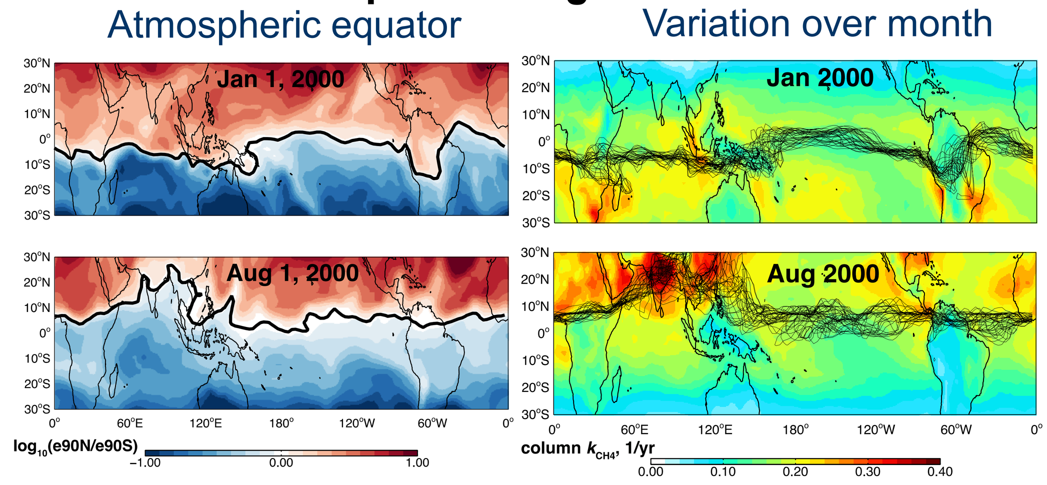
Natural tracers can constrain stratospheric motion and fossil CO_2



- ^{14}C tracks strat motion & fossil CO_2.
- ^{7}Be/^{10}B tracks stratosphere air in troposphere.

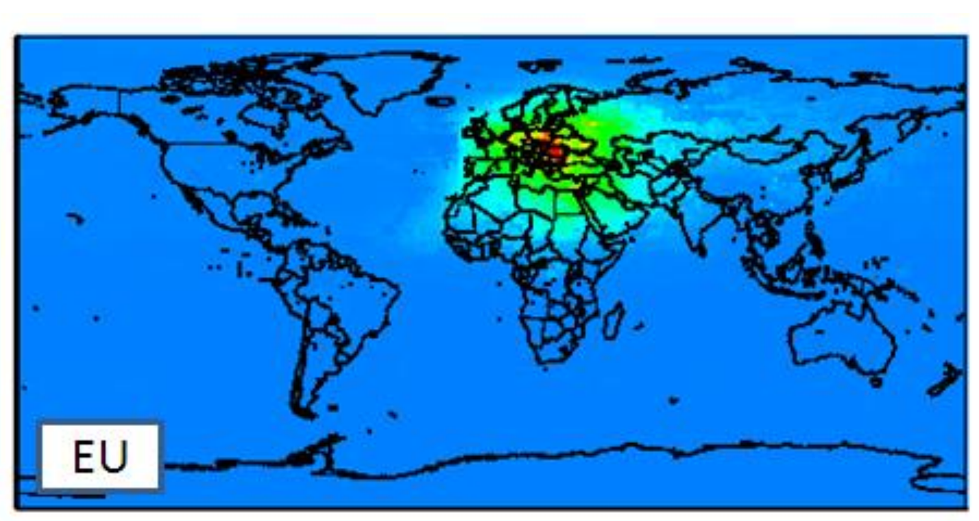
Kanu et al. (LLNL-UCBerkeley)

Idealized tracers can unambiguously identify tropical mixing barrrier



Tracers emitted north and south with 90-day decay.
Holmes & Prather (UC Irvine)

Tracers can be tagged in model to quantify contribution from source region or plant type



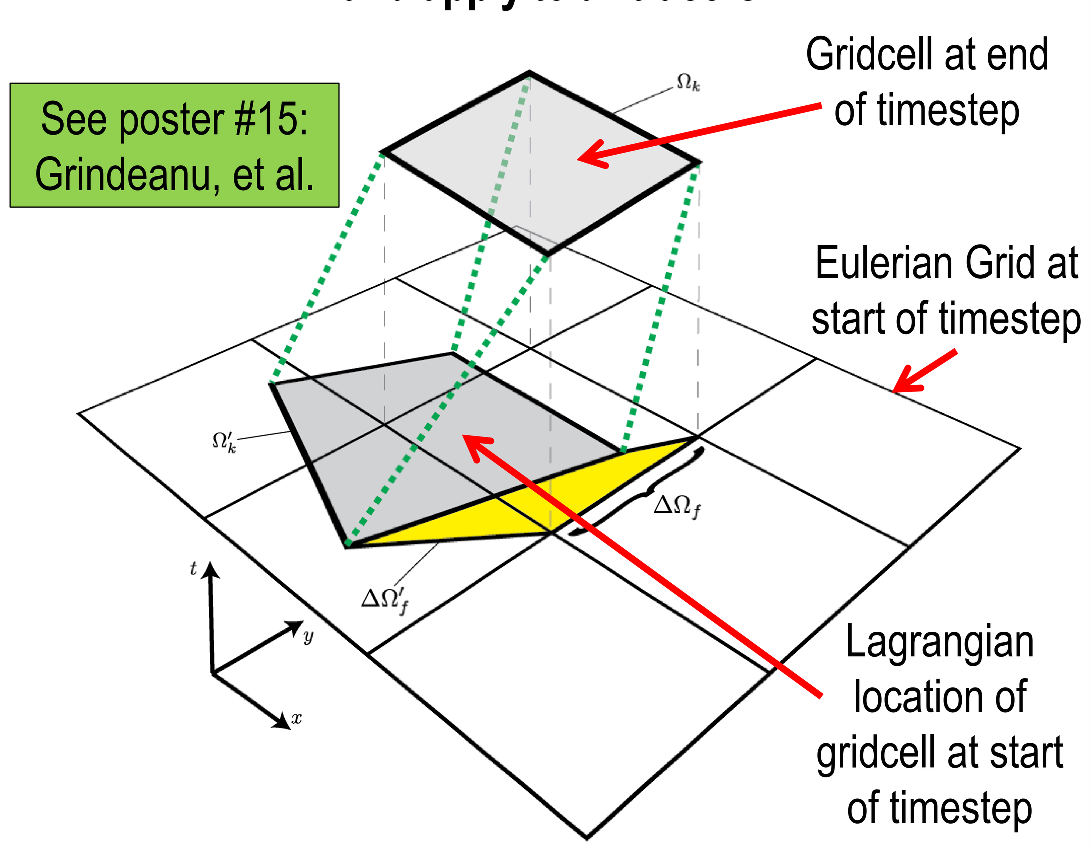
Effect of PM2.5 from European emissions
Anenberg, et al (2014)

Improving tracer performance with FASTMath & SUPER

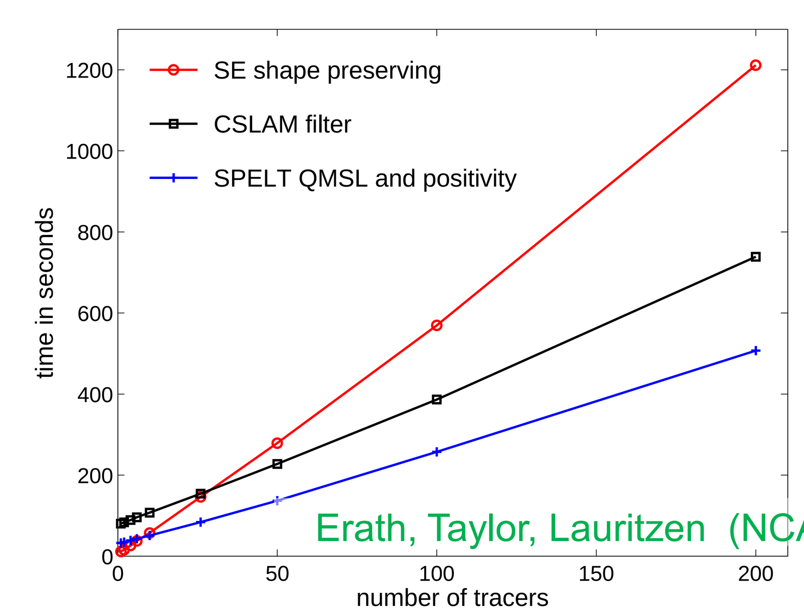
Existing tracer advection schemes usually solve the advection equations separately for each tracer, so computational cost scales linearly.

Using MOAB to solve advection once and apply to all tracers

See poster #15: Grindeanu, et al.

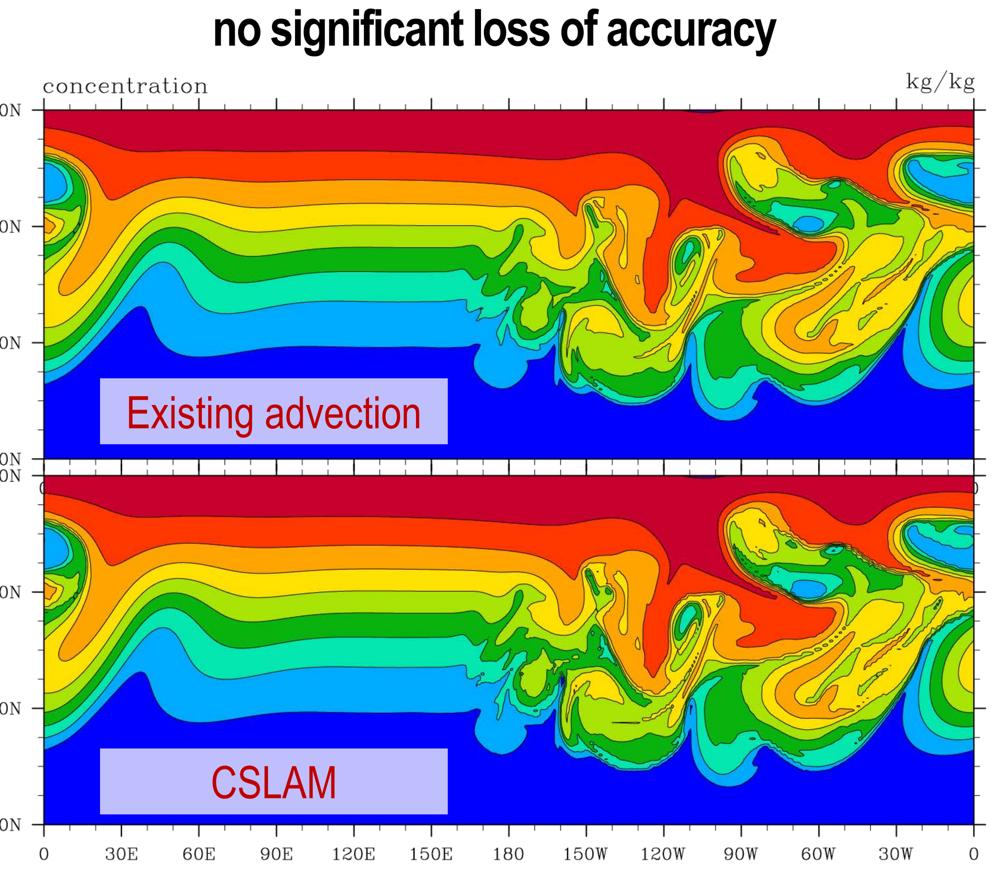


A simpler version (CSLAM) limited to neighboring gridcells (ie CFL=1), is working well.



Erath, Taylor, Lauritzen (NCAR & SNL)

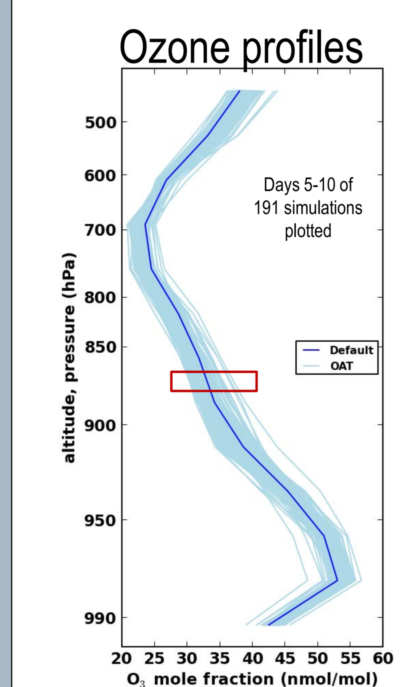
Comparison between advection schemes shows no significant loss of accuracy

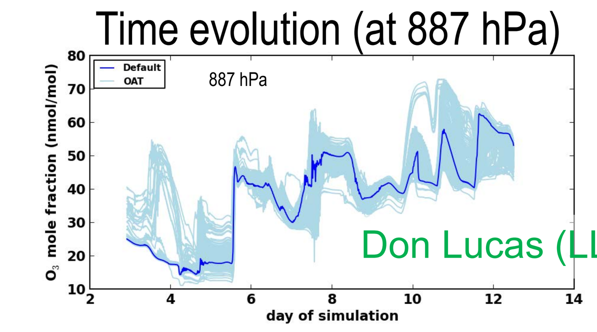


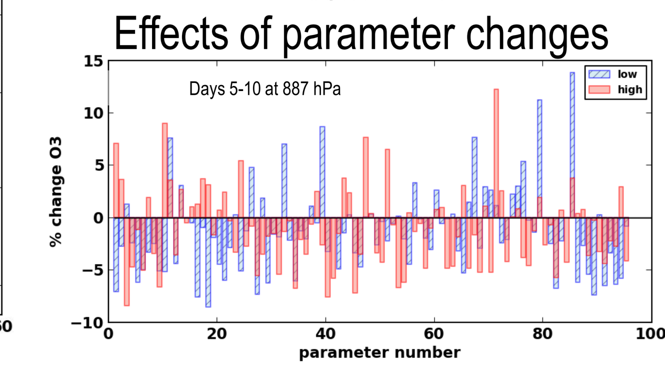
Erath, Taylor, Lauritzen (NCAR & SNL)

Uncertainty quantification, validation, & tuning with QUEST

Uncertainty in laboratory chemical rate constants results in significant differences in simulated ozone

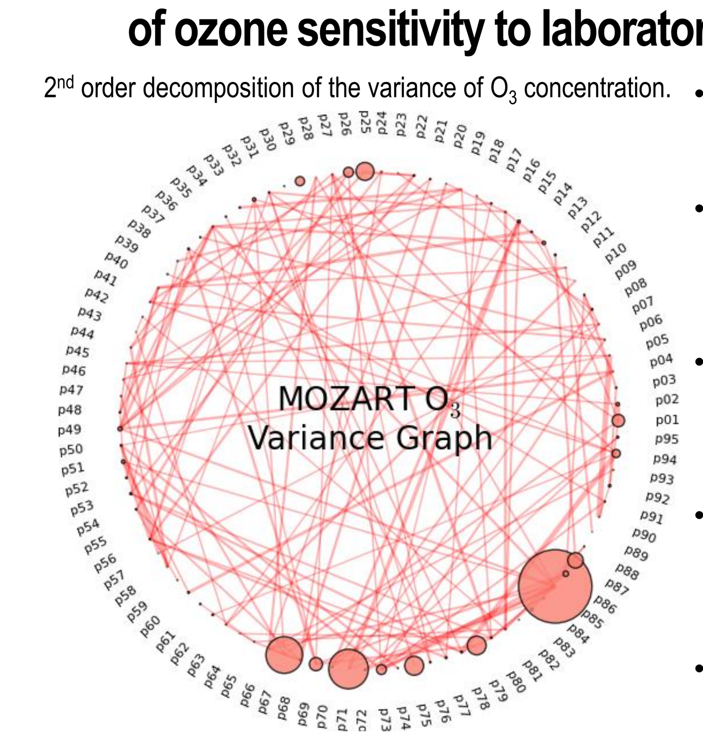






QUEST tools enable high dimensional UQ analysis of ozone sensitivity to laboratory parameters

2nd order decomposition of the variance of O_3 concentration.



- PDFs for 100 photochemical parameters.
- Ran ~10^4 ensemble column models using Latin hypercube sampling.
- Space complexity ~ O(NC^2)
  N = # training data
  C = # variance features
- MOZART graph
  N ~ 10^5 simulations
  C ~ 10^4 – 10^6
  (2nd – 4th order)
- Memory limits to 2nd order variance graphs .

Strategies to circumvent memory limitations

These problem sizes require 10-1000GB for 2nd to 4th order analyses. Hence, many computers limit our UQ variance analyses to low orders (e.g. Titan has 32GB per node). "Big data" machines have more memory (e.g. LLNL's Catalyst has 800GB per node). Sparse UQ methods that retain only the relevant information (e.g. compressive sensing) are being implemented to scale to even higher dimensions and orders.

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