From Arctic sea ice to carbon in the United States: New adventures in the world of CO_2 data assimilation

Hans Chen

Department of Meteorology
The Pennsylvania State University

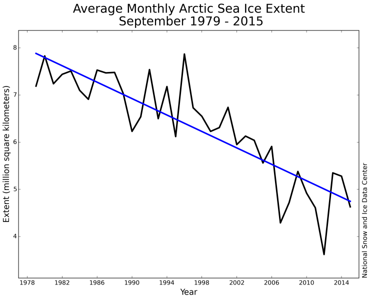
Recap: Arctic sea ice work

Santa's revenge: melting Arctic ice may be driving this winter's chill

Evidence is mounting that a warming Arctic has set the jet stream loose.

by **John Timmer** - Feb 17 2014, 7:00am EST

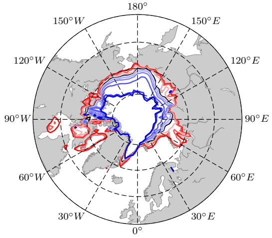
EARTH SCIENCE 197



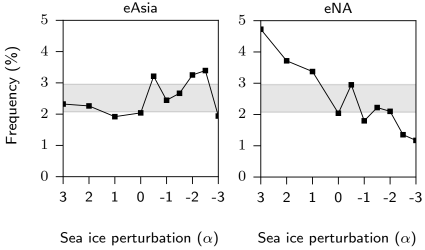
Ultimate question

Can sea-ice loss in the Arctic have a significant impact on the weather and climate that we experience here in the mid-latitudes?

Are the impacts of sea-ice loss robust?



Colder winters in mid-latitudes?



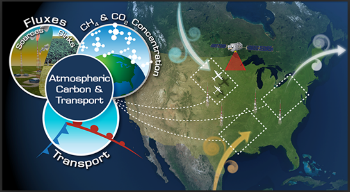
Conclusions

- Arctic sea-ice loss can lead to an increased frequency of extreme cold winters in eastern Asia under specific conditions
- Decreased Arctic sea ice generally results in less frequent extreme cold winters in eastern North America
- Remote responses are generally nonlinear and non-robust

NASA awards $30M grant to Penn State to help answer climate questions

UNIVERSITY PARK, Pa. -- Penn State will lead a five-year, $30 million mission to improve quantification of present-day carbon-related greenhouse gas sources and sinks. An improved understanding of these gases will advance our ability to predict and manage future climate change.

ACT-America will bring together more than 30 scientists from 10 institutions including federal agencies, national laboratories, other universities and private industry. NASA Langley Research Center, located in Hampton, Virginia, is Penn State's lead partner in the effort. Other Penn State researchers on the project include Thomas Lauvaux, adjunct professor of meteorology and researcher at NASA's Jet Propulsion Laboratory, California; Natasha Miles, research associate in meteorology; Scott Richardson, senior research associate in meteorology; Charles Pavloski, senior research associate in meteorology; Bernd Haupt, senior research associate, Penn State's Earth and Environmental Systems Institute Fuqing Zhang, professor of meteorology; and Klaus Keller, associate professor of geosciences.



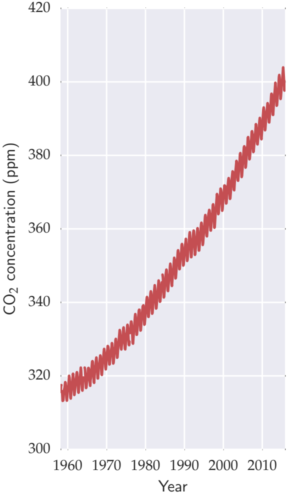
Understanding CO_2 fluxes is essential

Climate change

- Global carbon cycle
- Greenhouse gas balance
- Predicting climate change
- Regional impacts, e.g. ocean acidification

Policy making

- Limit greenhouse gas emissions
- Estimating and verifying emissions from countries



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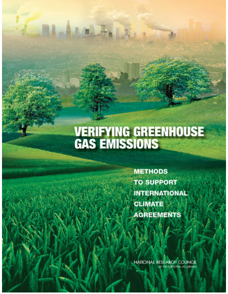
Deriving CO_2 fluxes is *hard*



"Uncertainties inferred from tracer-transport inversions are ... greater than 100 percent for anthropogenic CO_2 fluxes at national scales"

Challenges

- No observations of CO_2 fluxes
- Anthropogenic signal tiny compared to natural variability

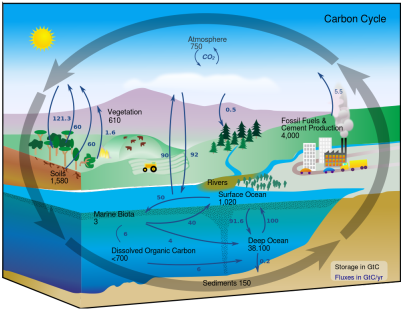
Promising future

- Pressing need to quantify and verify CO_2 emissions and fluxes
- Increasing amount of CO_2 concentration observations

Current solutions deriving CO_2 fluxes

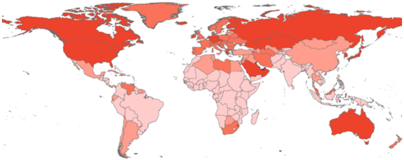
Terrestrial ecosystem model

- Model natural sources and sinks
- E.g. ocean, terrestrial biosphere, vegetation fires
- Note that the terrestrial sink is not modeled



Gridded inventories

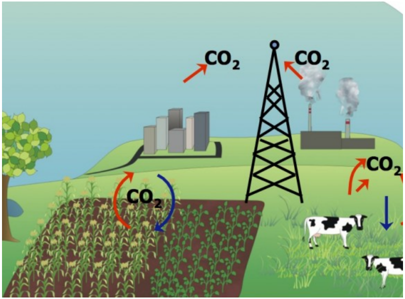
- Anthropogenic emissions
- Based on e.g. national economic and trade data



Current solutions deriving CO_2 fluxes

Inversion systems

- Use CO_2 concentrations to constrain fluxes
- Lagrangian model to track CO_2 transport backward in time
- Combine with fluxes using a Bayesian approach



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Current solutions deriving CO_2 fluxes

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Disadvantages

- Backward trajectory model different from forward model
- Computationally expensive for dense observations (e.g. from satellites)
- No uncertainties in the transport

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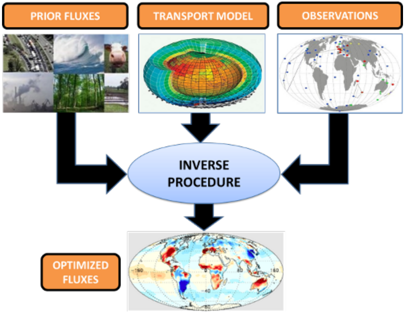

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Can we provide a better solution?

EnKF approach

- Run WRF-Chem with different CO_2 fluxes
- Take difference between observed and modeled CO_2 concentrations
- Update CO_2 fluxes based on difference and atmospheric transport

Essentially a parameter estimation of $F_{CO_2}(x, y, t)$

Advantages

- Straightforward to include different observations, e.g. towers and satellite
- Combines different sources of information in a coherent framework
- Computationally efficient for dense data
- Can include uncertainties in both fluxes and atmospheric transport

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Overview of strategy (subject to change)

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Assimilate CO_2 concentration in OSSEs where we know the true fluxes	→	Does our system work in the ideal world?
Assimilate real observations of CO_2 concentration from towers and satellite	→	How do the real CO_2 flux fields look like?
Include transport errors in the uncertainties of the optimized CO_2 fluxes	→	What are the uncertainties of the CO_2 fluxes?

OSSEs assimilating CO_2 concentrations

Goal

Prove that we can improve CO_2 flux fields by assimilating CO_2 concentrations in a set of Observing System Simulation Experiments

Details

- Over United States at the mesoscale (< 50 km)
- Examine impact of different observations (towers, satellite)

Procedure

- Assume prior fluxes represent the true fluxes
- Derive CO_2 concentration using WRF-Chem
- Run WRF-Chem with perturbed fluxes and assimilate CO_2 concentration with errors
- Use EnKF to derive new CO_2 fluxes

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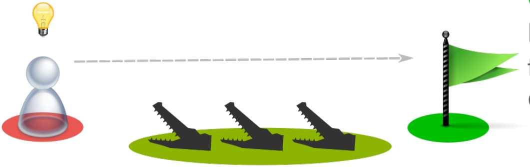

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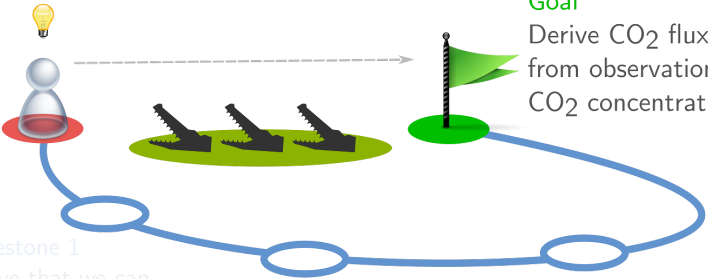

Goal
Derive CO_2 fluxes from observations of CO_2 concentration

Milestone 1
Prove that we can improve CO_2 fluxes by assimilating CO_2 concentration in a set of ideal experiments

Milestone 2
Derive real CO_2 fluxes using our EnKF system and CO2 concentration from towers and satellite

Milestone 3
Include atmospheric transport errors in the uncertainties of the optimized CO_2 fluxes

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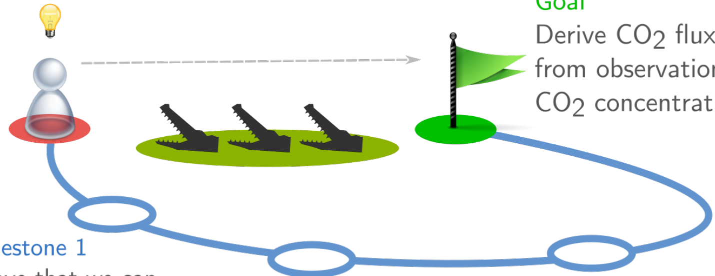

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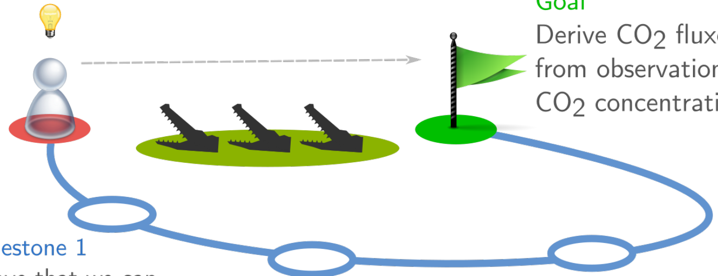

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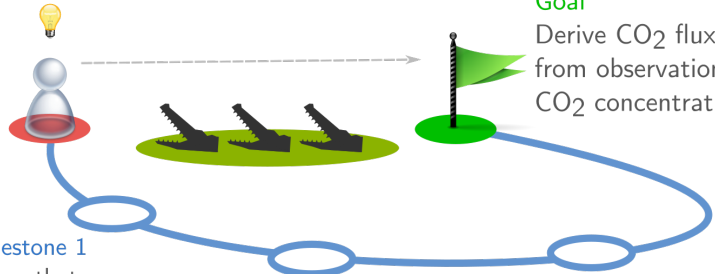

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