Given task:

Integration with ecosystem and land surface models

The motivation and history of ecosystem manipulation experiments

The future of experiments and the multifactor angle

Impacts of climate change experiments from acid rain to climate change and N cycling. Results, reflections on challenges and future directions exemplified by C balance studies
REVIEWS AND SYNTHESSES

Precipitation manipulation experiments – challenges and recommendations for the future

Abstract
Climatic changes, including altered precipitation regimes, will affect key ecosystem processes, such as plant productivity and biodiversity for many terrestrial ecosystems. Past and ongoing precipitation experiments have been conducted to quantify these potential changes. An analysis of these experiments indicates that they have provided important information on how water regulates ecosystem processes. However, they do not adequately represent global biomes nor forecasted precipitation scenarios and their potential contribution to advance our understanding of ecosystem responses to precipitation changes is therefore limited, as is their potential value for the development and testing of ecosystem models. This highlights the need for new precipitation experiments in biomes and ambient climatic conditions hitherto poorly studied applying
Our challenge - and response

Sitting on someone's shoulders

New times – new questions
New times – new new questions

Can example

Future
Our challenge - and response
Our challenge

Natural terrestrial feedback 20 times fossil fuel feedback
= small changes in natural feedback may offset all fossil fuel attempts
+ understanding C feedback may help mitigate

Reservoir sizes in GtC
Fluxes and Rates in GtC yr⁻¹

Denman et al., (2007) AR4
<table>
<thead>
<tr>
<th>Approach</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observations</td>
<td>1. Ultimate validation of ecosystem and global scale models</td>
<td>1. Long-term records rarely go back &gt;100 years</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Future responses are unknown</td>
</tr>
<tr>
<td>Gradients</td>
<td>1. Allow for evaluation of ecosystem response to different climates</td>
<td>1. Impossible to match sites perfectly</td>
</tr>
<tr>
<td></td>
<td>2. Allow for evaluating long-term effects</td>
<td>2. Sites have evolved with local climate over the millennia</td>
</tr>
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<td></td>
<td></td>
<td>3. No broad spatial gradients for CO₂</td>
</tr>
<tr>
<td>Experiments</td>
<td>1. Tool to evaluate cause-and-effect relationships</td>
<td>1. Step increases is not realistic</td>
</tr>
<tr>
<td></td>
<td>2. Tool to validate models</td>
<td>2. Can only realistically alter 2–3 factors</td>
</tr>
<tr>
<td></td>
<td>3. Provide opportunity for ‘surprises’</td>
<td>3. Can only generate short-term data on short-term response</td>
</tr>
<tr>
<td>Models</td>
<td>1. Integrate existing knowledge</td>
<td>1. Need to incorporate heterogeneity, disturbance etc.</td>
</tr>
<tr>
<td></td>
<td>2. Allow for projections in time and space</td>
<td>2. Not possible to validate longer-term effects</td>
</tr>
<tr>
<td></td>
<td>3. Provide for testing of conceptual and process understanding</td>
<td>3. Do not yet adequately incorporate biodiversity and stochastic events.</td>
</tr>
</tbody>
</table>
Sitting on someones shoulders
Sitting on someones shoulders

– where it all began
Sitting on someones shoulders

- acid rain

Risdalsheia, N (RAIN)

Gårdsjøn, S

Klosterhede, DK (EXMAN)

Paired catchments – e.g. Bear brook

Nitrogen – e.g. NITREX
Sitting on someones shoulders

- but

Everything has its time

- but we learned something

New times, new questions
New times, new questions

Climate change
– just some other drivers

CO₂

T

H₂O

Feedback

?
New times, new questions

H₂O
New times, new questions
New times, new questions
New times, new questions

Bringing things 2gether

Precipitation networks – Infrastructures – Databases
New times, new questions

Bringing things together

New times, new new new questions
New times, new new new questions

Individual treatments vs combination

Many

Few

Above ground

Below ground

Full combinations

Feedback

Individual treatments vs combination

Many

Few

Above ground

Below ground

Full combinations

Feedback

**New times, new new questions**

Individual treatments vs combination

Many

Few

Above ground

Below ground

Full combinations

Feedback
New times, new new questions

Multifactorial CC experiments

Jasper Ridge

OCCAM

TasFACE

SoyFace

CLIMAITE

New times, new new questions

- and new new answers
CaN example
FACE for CO₂
Passive night time for Warming
Automatic rainouts for drought

Temp elevated c. 1°C

Drought for 4-6 weeks in summer
(6-8% precip)

CO₂ enhanced (510 ppm)
Focus on carbon budget and quantify each process – or measure balance directly – Both is difficult
Getting the C balance

Mass balance equations

\[ \text{NPP} = \text{Pg} - R_a = \Delta C_{\text{plant}} + \text{Litter} \]

\[ \Rightarrow \text{Litter} = \text{Pg} - R_a - \Delta C_{\text{plant}} \]

\[ \text{NEP} = \text{NPP} - R_h - \text{DOC} = \Delta C_{\text{ecosystem}} \]

\[ \text{NEP} = \Delta C_{\text{SOM}} + \Delta C_{\text{plant}} \]

Change in SOM pool (DOC=0):

\[ \Delta \text{SOM} = \text{Pg} - R_{aA} - R_{\text{Soil}} - \Delta C_{\text{plant}} \]

Change in NEP (DOC=0):

\[ \Delta \text{NEP} = \Delta \text{SOM} + \Delta C_{\text{plant}} \]
Treatment effect on SOM pool:

\[ \Delta_T \Delta C_{SOM} = \Delta_T P_g - \Delta_T R_{aA} - \Delta_T R_{Soil} - \Delta_T \Delta C_{plant} \]
Getting the C balance

Annual upscaled flux (gC/m²/yr)

Canopy scaled input ($P_g$) and measured soil respiration ($R_s$)

Gross photosynthesis
Soil respiration

Averaged over ambient & elevated CO2

Elevated CO2 stimulates $R_s > P_g$

Balance ??

Albert et al., 2011, J. Pl. Phys.
Selsted et al., 2011, GCB

Ambient CO2
Elevated CO2

Δ = 300
Δ = 200

NOT true balance!!

Heterotrophic breakdown of SOM provides N to store more C than lost

\[ \Delta C_{\text{storage}} \quad 213 \text{ gC/m}^2\text{/yr} \]

\[ \Delta C_{\text{loss}} \quad 100 \text{ gC/m}^2\text{/yr} \]
Minimum and Maximum change in SOM

Min. change in SOM and NEP
\[ \Delta_T \Delta C_{\text{SOM}} = \Delta_T P_g - \Delta_T R_{\text{Soil}} \]
Carbon loss from SOM = 100 gC/m²/yr
\[ \Delta_T \text{NEP} = 100 \text{ gC/m²/yr} \]

Max. change in SOM and NEP
\[ \Delta_T \Delta C_{\text{SOM}} = - \Delta_T R_{\text{Soil}} \]
Carbon loss from SOM = 200 gC/m²/yr
\[ \Delta_T \text{NEP} = 150 \text{ gC/m²/yr} \]
<table>
<thead>
<tr>
<th></th>
<th>CO₂</th>
<th>Warming</th>
<th>Drought</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum SOM loss</td>
<td>100</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>∆NEP = 100</td>
<td></td>
<td>∆NEP = 20</td>
<td>∆NEP = 25</td>
</tr>
<tr>
<td>Maximum SOM loss</td>
<td>200</td>
<td>-80</td>
<td>-75</td>
</tr>
<tr>
<td>∆NEP = 150</td>
<td></td>
<td>∆NEP = -30</td>
<td>∆NEP = -40</td>
</tr>
<tr>
<td>&quot;likely&quot; SOM loss</td>
<td>170</td>
<td>-30</td>
<td>-45</td>
</tr>
<tr>
<td>∆NEP = 120</td>
<td></td>
<td>∆NEP = 0</td>
<td>∆NEP = 0</td>
</tr>
</tbody>
</table>
Increased SOM mineralisation
Mining and/or priming
Small changes in N and biggest by drought

Little link to carbon – do we understand nitrogen??
The Future
The Future

The challenge

Reservoir sizes in GtC
Fluxes and Rates in GtC yr⁻¹

Atmosphere
597 + 165

Vegetation, Soil & Detritus
2300 + 101 - 140

Weathering
0.2

Respiration
119.6

GPP
120

Land sink
2.6

Land Use Change
1.6

Weathering
0.2

Rivers
0.8

Surface Ocean
900 + 18

Intermediate & Deep Ocean
37,100 + 100

Surface sediment
150

Fossil Fuels
3700 - 244

Marine Biota
3

50

39

11
Single factor understanding overpredict effects (experiments + models)

Multifactoriality

Leuzinger et al. (2011) TREE

Larsen et al. (2010) GCB

The Future
Long term understanding require long term experiments

Repeated "normal" droughts (5 yrs – INCREASE/VULCAN project)

Changes in "soil structure"

"Keep it going"
 Proper C quantification

Reservoir sizes in GtC
Fluxes and Rates in GtC yr⁻¹

Atmosphere
597 + 165

Vegetation, Soil & Detritus
2300 + 101 - 140

Weathering
0.2

Respiration
0.4

0.8

Atmosphere
597 + 165

Vegetation, Soil & Detritus
2300 + 101 - 140

Land sink
2.6

Land Use Change
1.6

70.6

70

22.2

20

6.4

Fossil Fuels
3700 - 244

Surface Ocean
900 + 18

Intermediate & Deep Ocean
37,100 + 100

Surface sediment
150

Marine Biota
3

50

39

11

The Future
Ecosystem complexity is enormous
Models are only way we can handle the complexity

*Climate change (CO₂, T, H₂O)*

*Photosynthesis*

*Plant chemistry*

*Litterfall & Chemistry*

*Species change*

*Soil Chemistry*

*Microbes*

*Leaching*

*Consequences ??*

(Ironic my talk did not include any model output 😐)

Integrating models in experiments MUCH more and MUCH better

We need a dynamic biological systems approach.
"Killing fields"

Our experiment window

Xeric
Usually stressed

Mesic
Seldom stressed

Hydric
Usually stressed

The Future


The Future

Understanding Global Change....

- Acid Rain
- N Deposition
- Atmospheric CO₂
- Warming
- Precipitation
- Extremes
- Other?


The Future

We need

• multifactor,
• long term
• thresholds & extremity testing experiments
• with proper C counting (and N interaction)
• and linked to models with
• biological interactions

- and (I believe) we can do it if we stick together

Thanks for your attention

- and thanks to colleagues and friends involved in EXMAN, NITREX, NEU, C-EXTREME, TERACC, INTERFACE, PRECIPNET, CLIMMANI, INCREASE, Gårdsjön, CLIMEX ..........

www.climaite.dk

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