Atmosphere – Land Surface Interactions: Why do we Need Long-Term Observations?
What do we get out of long-term observations?
Intellectual Motivations and Practical Benefits

Intellectual Motivations for Long-Term Observation Programs

- **Systems Dynamics**: Temporal scales of ecosystem – atmosphere interactions
- **Diagnostic Science**: Detection of trends and analysis of global change impacts
- **Environmental Science Methodology**: Non-manipulative field experimentation

Practical Benefits of Long-Term Observation Programs:

- **Enhance knowledge** of complex exchange and transformation processes
- **Database** for model development and testing
- **Benchmark** for global coverage satellite observations
- **Training ground** for young scientists and environmental engineers
Socio-economic processes (society’s memory) tick on a much shorter time scale than their consequences in the environment: We are not very good at thinking in terms of long time effects!

(source: IPCC 2001, WG1 Report, Summary)
Process Knowledge of Land-Surface-Atmosphere Interaction is Recent

The Development of Climate models, Past, Present and Future

(mid-1970s)
- Atmosphere
- Land surface
- Ocean & sea-ice

(mid-1980s)
- Atmosphere
- Land surface
- Ocean & sea-ice

(early 1990s)
- Atmosphere
- Land surface
- Ocean & sea-ice

(late 1990s)
- Atmosphere
- Land surface
- Ocean & sea-ice
- Sulphate aerosol
- Non-sulphate aerosol

(present day)
- Atmosphere
- Land surface
- Ocean & sea-ice
- Sulphate aerosol
- Non-sulphate aerosol
- Carbon cycle
- Dynamic vegetation

(early 2000s?)
- Atmosphere
- Land surface
- Ocean & sea-ice
- Sulphate aerosol
- Non-sulphate aerosol
- Carbon cycle
- Dynamic vegetation

(source: IPCC 2001, WG1 Report, Summary)
Short-Term vs. Long-Term Observations
In search of the "Ensemble": all possible states of a system

- individual short campaigns show development and transformation paths
- may be disjunct; generalities not evident: case studies

(from Wallace and Hobbs, 2006, Fig. 7.26)

- long-term observations (may) make patterns, generalities evident
- provide a more complete view of the system
- improve model development and testing capabilities
Example: Forest-Atmosphere Exchange of CO$_2$ (FLUXNET)

MMSF Site, Indiana (USA), 1998 – (continuing)
Cumulative Exchange of CO₂ over 9 Years (MMSF)

NEE: *Net Ecosystem Exchange* = Respiration - Assimilation

<table>
<thead>
<tr>
<th>Year</th>
<th>Cumulative NEE (ton C ha⁻¹)</th>
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<tbody>
<tr>
<td>1998</td>
<td>236 [g(C)m⁻²]</td>
</tr>
<tr>
<td>1999</td>
<td>367 [g(C)m⁻²]</td>
</tr>
<tr>
<td>2000</td>
<td>267 [g(C)m⁻²]</td>
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<tr>
<td>2001</td>
<td>304 [g(C)m⁻²]</td>
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<tr>
<td>2002</td>
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<td>2003</td>
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<td>2004</td>
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<tr>
<td>2005</td>
<td>386 [g(C)m⁻²]</td>
</tr>
<tr>
<td>2006</td>
<td>360 [g(C)m⁻²]</td>
</tr>
<tr>
<td>2007</td>
<td>304 [g(C)m⁻²]</td>
</tr>
</tbody>
</table>

Sum of ca. 79'000 hourly CO₂ flux measurements

**Business as usual?**

**Sudden regime change?**

30 tons C ha⁻¹
Annual Net Ecosystem Production (NEP)

Detection of unexplained variation: opportunity for new insights into ecosystem function

1999-2003:

$\mu_{\text{NEE}} : 316 \text{ g(C)m}^{-2}\text{a}^{-1}$

$\sigma_{\text{NEE}} : 44 \text{ g(C)m}^{-2}\text{a}^{-1}$
What can cause these Effects?

... 2004 was the Year of the Brood X Cicada

entirely new and unexpected linkages and mechanisms are being considered (work in progress...)

17 year periodical cicada: next emergence in 2021
Example: Forest-Atmosphere Exchange of N$_2$O (NitroEurope)

Höglwald Site, Upper Bavaria, 1994 – (continuing)
N$_2$O Emissions at Höglwald Forest Long-Term Site

- **Spruce Control**: "business as usual"
- **Selective Cutting**: characterized by episodic bursts (thawing events)
- **Clearcut**: steep rise & gradual decline over years

The graph shows the emissions over time for different cutting methods at the Höglwald Forest site.
N$_2$O Emissions at Höglwald Forest Long-Term Site

2006 short-term thaw events

Episodic events: contribute 50-80% of cumulative flux

Impact of episodic events detected only due to continuous, long-term observation

leads to detailed process studies, lab experiments and model development
Conducting Science in the Environment?
We do not have replicates of the atmosphere, of climate….

- **Long time series** in place of experimental replica
- **Conditional data selection** (out of collected time series) in place of experimental control:
- **Field experiments** in place of laboratory experiments

Long-term observations provide an essential methodology for environmental science

source: Science, 22 Aug. 2008, cover
Thank you for your attention!