Designing Monitoring Systems to Detect Trends: Setting Quantitative Criteria

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Designing Monitoring Systems to Detect Trends

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CO₂ Concentration (ppmv)

Year


310 320 330 340 350 360 370
Trend Detection

- “Finding a change which is large relative to natural variability.”
- Both the magnitude of variability and the memory hinder our ability to detect trends.
- Finding a change which is large relative to natural variability and instrument uncertainty.
Number of Years needed to detect a trend

- **Approximately:**

\[ n = \left\{ \frac{2 \sigma_n}{|\omega_o|} \sqrt{\frac{1 + \phi}{1 - \phi}} \right\}^{2/3} \]

- Assuming that detection is declared at the 95% confidence level
- This estimate allows for 50% likelihood of detection
### Years to Detect .2 Degrees per Decade Trend in Temperature

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<td>5</td>
<td>63</td>
<td>77</td>
<td>100+</td>
<td>100+</td>
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Visual Example

- How many years does it take to detect a trend in ozone?
- Use our understanding of variability;
- Use our understanding of the predicted trends
- Estimate visually how long it will take to detect a trend.
Metric: Number of years

- Our ability to detect trends is limited by natural variability.
- We can estimate how long it will take to detect trends.
- Some parameters, some places, some monitoring approaches may take considerably less time than others.
What can we control?
We can control only four aspects of monitoring to detect trends

- **Where we monitor**
- **What frequency**
- **What accuracy**
- **What we monitor**
Where do we monitor?

- Some places are inherently better for detecting trends than others.
- Monitoring by satellite involves averaging over height, longitude and latitude.
  - Measurement smoothing can damage our ability to detect trends.
How many single stations do we need?

- Spatial coherence means that averaging many different locations does not always reduce error bars significantly.
- Spatial coherence can be estimated from past data.
MSU Channel 4
Correlation with S.F.
How does spatial redundancy affect our ability to detect trends?
82 Station Subset of HCN Network
225 Station Subset of HCN Network
We can control only four aspects of monitoring to detect trends

- Where we monitor
- What frequency
- What accuracy
- What we monitor
What frequency?

- Inherent memory in environmental data results in redundancy of measurements.
- Daily data may be more than needed.
- Less than daily measurements may obscure diurnal trends
STERLING (WASH DULL 0 Z temp)
Lat. = 38.98  Long. = -77.47
STERLING (WASH DULL 0 Z)
Lat. = 38.98     Long. = -77.47

Surf.

1000 900 800 700 600 500 400 300 200 100


Weatherhead   Wed Mar 13 13:36:18 2002
How do the trends change when we take data less frequently than every day?
How long will it take to detect trends?
Years to Detect 0.2 degrees per Decade
Dulles 0Z 500 mb

measured years

Weatherhead Wed Jun 5 12:45:30 2002
How does frequency of measurement affect how long we will have to monitor to detect trends?

In general: Monitoring less frequency:

- Increases magnitude of variability (bad for trends)
- Decreases autocorrelation (good for trends)
- Reduces representativeness (do we really know what happened?)
We can control only four aspects of monitoring to detect trends

- Where we monitor
- What frequency
- What accuracy
- What we monitor
What accuracy?

- Relative accuracy is all that’s needed for trend detection.
- Relative accuracy is extremely hard to maintain for decades without absolute accuracy.
- Improved accuracy may save decades in monitor or may be irrelevant.
Case Example

- Uncertainty: ±2% ; Trend: 4% per decade
- Result:
  - First ten years of data are still unsubstantial
- Improving Accuracy to ±1% saves five years of monitoring
Measurement Uncertainty is Not Generally Random

- Trends generally require decades to detect
- Reference instruments and calibration mechanisms often change over the period of several decades
- Most materials for both instrumentation and calibration drift or shift preferentially in one direction
Absolute Accuracy vs. Precision

- Absolute Accuracy is generally larger than precision
- Precision, or repeatability, is all that is needed to detect relative trends.
- Over many decades, repeatability is extremely hard to quantify without absolute accuracy
- Some estimate of uncertainty for the full time period must be established
Number of Years

- Approximately:

\[
n = \left\{ \frac{(2 \cdot \sigma_n / |\omega_o|)}{\sqrt{1+\phi}/(1-\phi)} \right\}^{2/3} + 2 \cdot \text{uncertainty}_\pm / |\omega_o|
\]

- Assuming that detection is declared at the 95% confidence level
- This estimate allows for 50% likelihood of detection
Is accuracy ever the limiting factor in detecting trends?
Wind-induce undercatch: WMO intercomparison results

![Graph showing the ratio of gauge catch to the DFIR against wind speed at gauge height (m/s). The graph compares various gauges: Canadian Nipher, NWS 8" Alter, NWS 8" unsh, Hellmann unsh, and Tretyakov. Each gauge is represented by a line with different markers and colors.]
Accuracy directly influences our ability to detect trends

- In some cases, our measurement uncertainty is considerably larger than the signal we detect
- Estimating appropriate measurement uncertainty over decades of monitoring is extremely
We can control only four aspects of monitoring to detect trends

- Where we monitor
- What frequency
- What accuracy
- What we monitor
Is there a canary parameter?

What is meant by this?

A parameter where the signal is considerably larger than the variability.*

A parameter where change can only imply anthropogenic influence
- this requires considerably understanding over long time scales.

A parameter where a change can imply significant changes at the Earth’s surface.

* and measurement uncertainty?
What we monitor

- Change is expected in many parameters: temperature, water vapor, dynamics, trace gases, cloud cover, radiation, etc.
- What we monitor is key to understanding causes of change.
- Trends can be detected earlier if we can remove some of the variability.
Optimization

- More sites or higher accuracy?
- More frequent measurements at a few sites or more sites?
- Higher vertical resolution or higher photon count (accuracy)?
Improved Accuracy or More Sites?

**Improved Accuracy**
- Clearer understanding of what we’ve measured
- Costs often increase exponentially
- Time for trend detection decreases

**Additional Sites**
- Costs increase in a known manner
- Time for trend detection decreases - usually slightly
- Representativeness improves and expands
- “Insurance” for site failures
Conclusion

1. Trends are difficult to detect:
   - Small trends, large variability, measurement uncertainty.

2. We can control only four aspects to detect trends:
   - Location, frequency, accuracy, parameters

3. We can optimize systems to detect trends most efficiently with the following benefits:
   - Answering scientific questions earlier
   - Confirming, improving models
   - Allowing for earliest policy decisions
   - Maintaining prudent use of available funds