Spatial and Temporal Considerations for a Reference Network

Betsy Weatherhead
Mauna Loa, Hawaii

![Graph showing CO₂ concentration over time (ppmv) from 1950 to 2000. The concentration increases steadily from approximately 310 to 370 ppmv. Source: Dave Keeling and Tim Whorf (Scripps Institution of Oceanography).](image-url)
Nature’s response is not always so linear.

Global air temperature
2000 anomaly +0.29°C
(6th warmest year on record)
Sonde Temperature Trends (C/decade) at 0 Z

COLD BAY
CDB -162.72 55.2

MCGRATH
MCG -155.62 62.97

YAKUTAT
YAK -139.67 59.52

SACHS HARBOUR
YSY -124.73 71.95

OAKLAND
OAK -122.2 37.73

GUADALUPE ISLAND
IGP -118.25 28.87

DESERT ROCK/MERCUR
DRA -116.02 36.62

FT SMITH (UA)
YSM -111.95 60.03

LANDER
LND -108.72 42.8

CHIHUAHUA
MCV -106.07 28.63

AMARILLO
AMA -101.7 35.23

DODGE CITY
DDC -99.97 37.77

FT WORTH/CARSWELL
FWH -97.45 32.77

RESOLUTE
YRB -94.92 74.68

INTERNATIONAL FALL
INL -93.38 48.57

TROUT LAKE
YTL -89.87 53.83

GREEN BAY
GRB -88.13 44.48

EUREKA
YEU -86.18 80.22

CORAL HARBOUR
YZS -83.37 64.2

KEY WEST/BOCA CHIC
NQX -81.7 24.58

MIAMI
MIA -80.28 25.82

BUFFALO/GRTR ARPT
BUF -78.73 42.93

MANIWAKI
YMW -75.97 46.38

NEW YORK/IDLEWILD
ILW -73.78 40.67

SANTO DOMINGO
SDQ -69.88 18.47
Sonde Temperature Trends (C/decade) at 0 Z
Are there patterns?
Sonde Temperature Trends (C/decade) at 12 Z

- NOME FED BLDG (OME -165.4 64.5)
- POINT BARROW (BRW -156.78 71.3)
- NAKNEK (AKN -156.65 58.68)
- LANDER (LND -108.72 42.8)
- GRAND JUNCTION (GJT -108.53 39.12)
- EL PASO (ELP -106.4 31.82)
- DAYTON/WRIGHT PATT (DAY -84.12 39.87)
- HUNTINGTON (HTS -82.55 38.37)
- PITTSBURGH/PITTSBG (PIT -80.22 40.5)
What is the primary goal of a Reference Network?

- Detection of Representative Trends?
  - Spatially: site in representative areas
  - Temporally: monitor consistently to establish trends

- Understand errors and transfer standards?
  - Spatially: site with existing instrumentation and expertise
  - Temporally: make measurements when they can add to knowledge.
Trend Detection

- “Finding a change which is large relative to natural variability.”

- For environmental data both the magnitude of variability and the memory (autocorrelation) hinder our ability to detect trends.
The key

- All four parameters which affect our ability to detect trends vary by location:
  - Magnitude of variability
  - Autocorrelation
  - Size of the trend
  - Stability of the measurements
One example: temperature trends

- Temperature trends are predicted by a number of different models.
- How long will we need to monitor to detect trends?
As for most environmental data, trends are usually derived using a statistical model such as:

Temperature = trend + seasonal + Noise

- Where the trend may be linear or not.
- Where the noise involves both the magnitude of variability and autocorrelation.
Estimating the Number of Years for Trend Detection

- If we understand the size of trend we are looking for;
- If we know the typical magnitude of variability;
- If we know the amount of temporal memory in the system;
- We can estimate how long we need to monitor.
Number of Years needed to detect a trend

- Approximately:

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

- 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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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.
SBUV OZONE TOTAL COLUMN OZONE - 40N

Original Monthly Averaged Data

Monthly Means Removed, Lowess Line Fit Superimposed
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

- What we monitor
- What accuracy
- Where we monitor
- What frequency
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: \( \pm 2\% \); Trend: 4\% per decade

- Result:
  - First ten years of data are still unsubstantial

- Improving Accuracy to \( \pm 1\% \) saves five years of monitoring
GSFC Predictions - without climate change

GSFC Predictions with SBUV Lowess Residuals

with +-1% error plus +-1% drift
Incorporating Long Term Stability estimates in our estimate of our ability to detect trends

- In some cases, our measurement uncertainty is considerably larger than the signal we want to detect.
- Estimating appropriate measurement uncertainty over decades of monitoring is extremely difficult.
- Measurement stability and statistical variability are likely to be independent, thus:

\[ \sigma^2_{\text{total}} = \sigma^2_{\text{statistical}} + \sigma^2_{\text{stability}} \]

For temperature: 0.1 may add ten years to monitoring
For humidity: uncertainty is larger.

Identifying a metric gives guidance to decision making and resource allocation.
We can control only four aspects of monitoring to detect trends

- What we monitor
- What accuracy
- Where we monitor
- What frequency
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.
Where do we monitor:

single locations

- Some places are inherently better for detecting trends than others.
- Natural variability, memory and magnitude of trend vary by location.
- The difference in number of years can vary by more than a factor of two.
Magnitude of temperature swings

Channel 2 St.Dev.
Autocorrelation of monthly data

Channel 2 Autocorrelation
Channel 2: Years to Detect 0.2 deg/decade
MSU channels 2 & 4 characteristics

Channel 2 St.Dev.

Channel 4 St.Dev.

Channel 2 Autocor.

Channel 4 Autocor.
Looking in the vertical

- Near constant trends are predicted throughout the troposphere

- Is there an optimal place to detect trends?
Years Saved by Monitoring Free Troposphere 0Z

Weatherhead  Tue May 21 12:14:04 2002 True Range of Data: (3 to 36)
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.
MSU Channel 4
Correlation with lat=0 and long=0
How does spatial redundancy affect our ability to detect trends?
82 Station Subset of HCN Network
225 Station Subset of HCN Network
U.S. Annual Temperature Series

Anomaly (°C)

From Laura Hinkelman
Deseasonalized Selected (W m^-2)

From Laura Hinkelman.
Redundancy in Surface Data for Proposed Locations.
Choosing locations for monitoring

- Some locations are better than others for detecting trends.
- Sub-regional differences are likely small.
  - Define spatial scales
- What is the primary goal:
  - Estimating global change
  - Annual/seasonal/diurnal trends?
  - Understanding specific regional change
    - QBO, AO, NAO, ENSO effects?
  - Transferring standards/understanding errors.
- Once the goal is clear, we can quantify the best approach.
We can control only four aspects of monitoring to detect trends

- **What we monitor**
- **What accuracy**
- **Where we monitor**
- **What frequency**
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 changes.
Monthly Deseasonalized Averages, 500 mb Temperature, Dulles
How do the trends change when we take data less frequently than every day?
How do the error bars on our trends change when we take data less frequently than every day?
Estimated Error in 500 mb Temperature Trend (2 sigma)

Dulles

2*s.d.
How long will it take to detect trends?
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?)
Decreasing the data frequency

- We can estimate the cost (in number of years of monitor) to decrease the data frequency.
- Decreasing the data frequency can reduce our ability to:
  - Detect extreme events
  - Detect diurnal (or perhaps seasonal) signals
We can control only four aspects of monitoring to detect trends

- What we monitor
- What accuracy
- Where we monitor
- What frequency
Integration

- We make choices about all four of the parameters we control.
- These choices have direct impact on how long we will likely need to monitor in order to detect trends.
- Optimal choices exist.
  - e.g. More sites or higher accuracy?
- All choices will affect our ability to detect trends and the scientific questions we may ask of the emerging data.
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. We can control only four aspects to detect trends:
   - What we monitor; Where we monitor;
   - What frequency; What accuracy

2. We can optimize systems when we have a clear goal.
   - Establish accuracy and transfer ability
   - Establish global trends
   - Establish regional trends
   - Monitor key climate features

3. Optimization provides the following benefits:
   - Answering scientific questions earlier
   - Confirming, improving models
   - Allowing for earliest policy decisions
   - Maintaining prudent use of available funds