NPL

National Physical Laboratory

About NPL …

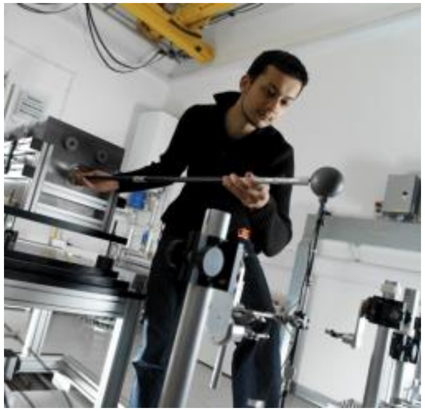
NPL National Physical Laboratory

The UK’s national standards laboratory

- Founded in **1900**
- World leading **National Measurement Institute**
- ~750 staff; 550+ specialists in Measurement Science plus 200 visiting researchers pa
- State-of-the-art laboratory facilities
- 388 Laboratories (35,746 sq. metres)
- The heart of the UK’s **National Measurement System** to support business and society
- Experts in **Knowledge Transfer**

What do we do

- Develop & disseminate UK's measurement standards, ensure they are internationally accepted
- Multidisciplinary R&D and technical services for public and private sector
- Knowledge transfer and advice between industry, government and academia
- Promotion of science and engineering




SI Units

NPL National Physical Laboratory

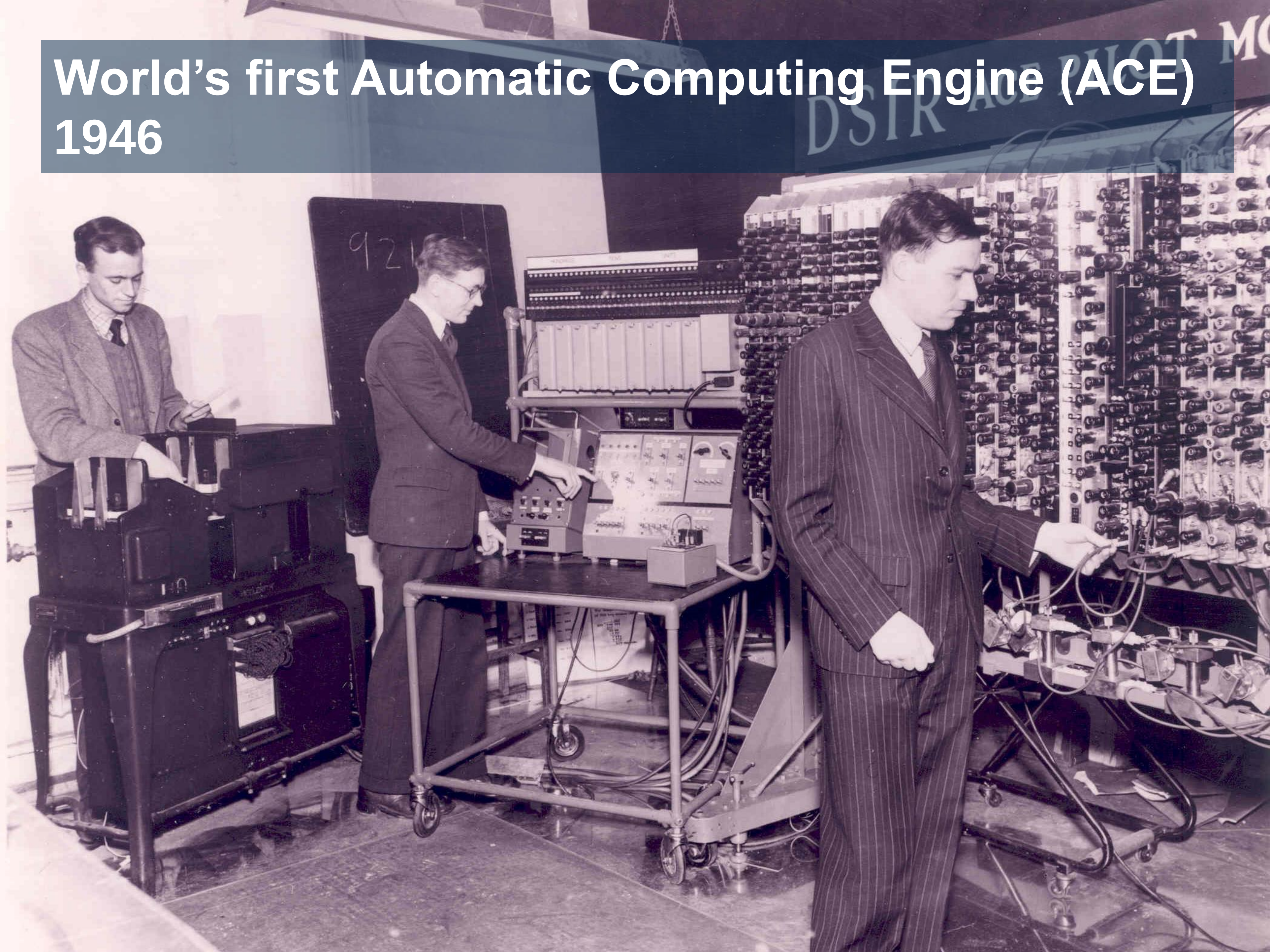
kg	kilogram	Mass
m	metre	Length
s	second	Time
A	ampere	Electric Current
K	kelvin	Temperature
cd	candela	Luminous Intensity
mol	mole	Amount of Substance

NPL's Calibration Services

National Physical Laboratory

- Mass
- Neutrons
- Photometry
- Radioactivity
- Radiometry
- RF & microwave
- Spectrophotometry
- Thermal
- Time & frequency
- Optical power and frequency
- Laser measurements
- Force & pressure
- Infra-red radiation
- Ultrasonics
- Gas standards
- Ionising radiations
- Acoustics
- DC & LF
- Fibre optics

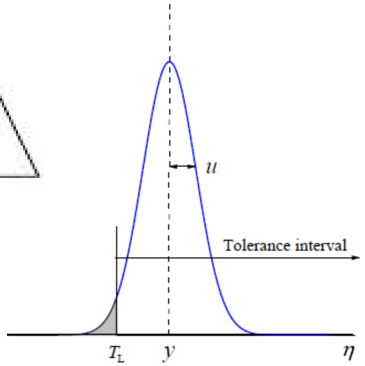
World’s first Automatic Computing Engine (ACE) 1946

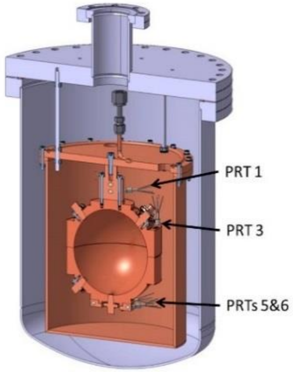


Packet-switching developed at NPL 1966

Data science

- Ensuring measurements are traceable to standard units
- Ensuring inferences, predictions and decisions are quality-assured
- Measurements made inside the laboratory
  “theory-heavy, data-light”
- Measurements made outside the laboratory
  “theory-light, data-heavy”





Promoting confidence in (the use of) data

- Measuring and transmitting data
  - Integrity and security of data
  - Providing legitimate access to data and information
  - Detecting faults, corruption, malicious interventions

- Storage and retrieval of data
  - Provenance of data
  - Metadata: when, where, how it was captured
  - Cleaning and curating data

- Data analytics
  - Extracting knowledge from data
  - Uncertainty quantification, with contributions from data, models, algorithms, computation, training sets, software, etc.

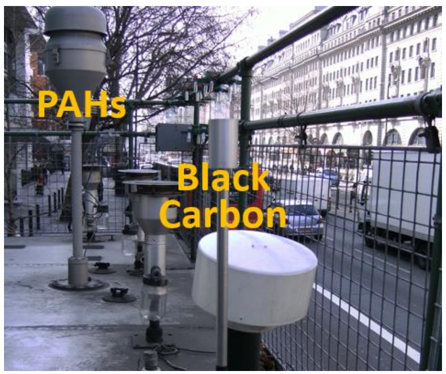
Sensor networks

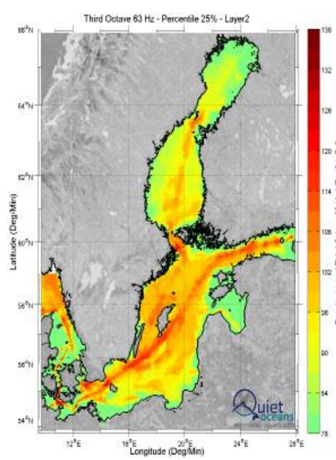
- Collection of (often) many low-cost sensors making discrete measurements (in space, time and frequency) of quantities that vary continuously (in space, time and frequency)
- Can operate at different scales (factory, neighbourhood, city, region, global)
- Source of large volumes of data
- Want to use data to make predictions and decisions, for source identification and attribution, all supported by statements of uncertainty

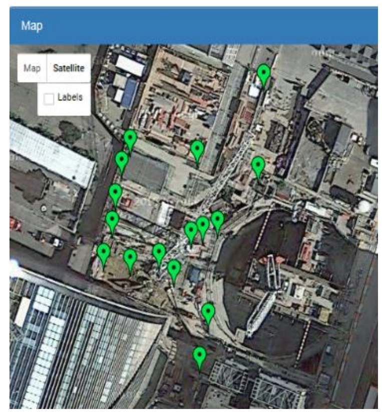
Examples

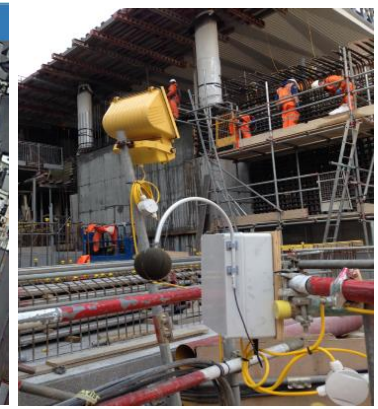
NPL
National Physical Laboratory

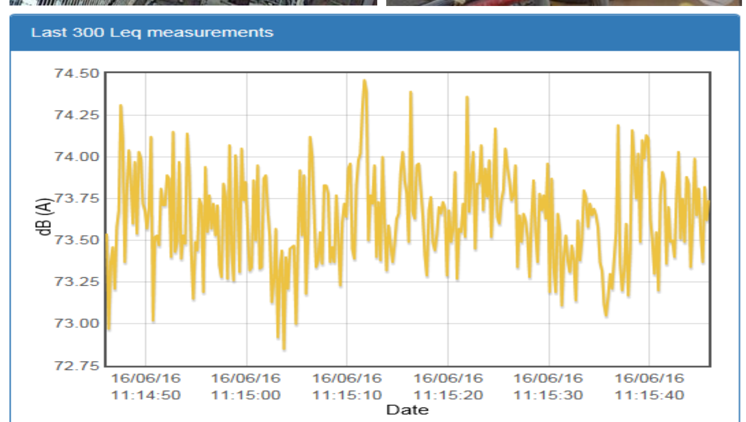
- Underwater acoustic noise in oceans
- Air quality and airborne noise in urban environments
- Radiometric measurements from satellites for EO





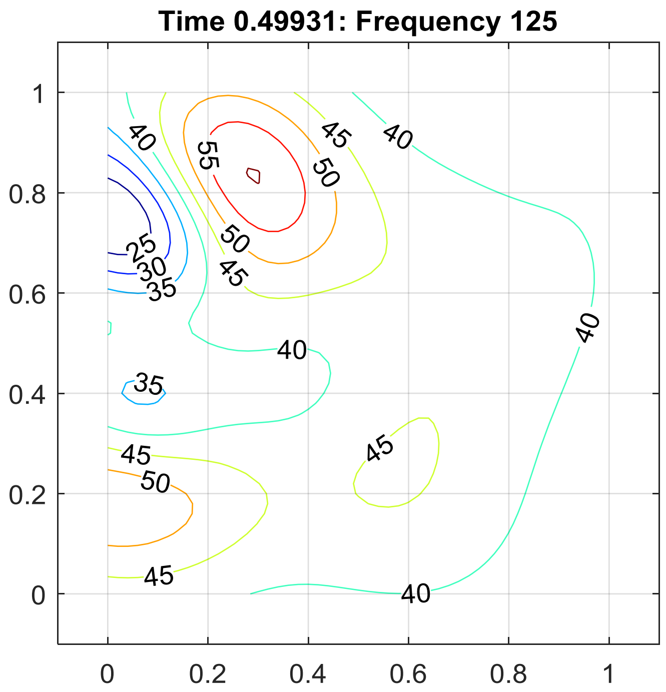


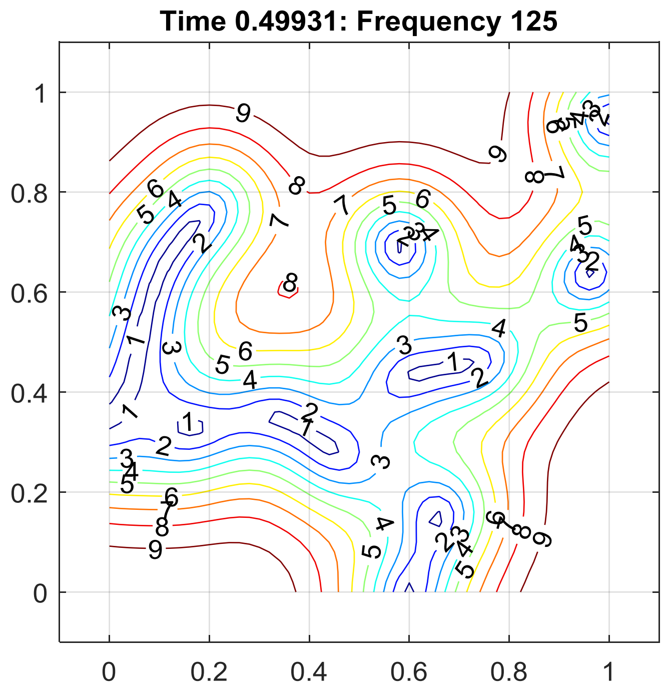




Prediction problem

- Create spatial-temporal-frequency maps of both estimates and uncertainties for measured quantities
- Can we exploit the co-location of sensor networks operating with different modalities (measuring different quantities that are dependent)?





Prediction problem

- GPs a useful tool but can be difficult to apply when the size of the training set exceeds a few thousand

  (Example of airborne acoustic network provided 500,000 measured values per day for many weeks)

- Given training set (X, y), a GP with covariance function $k(x_1, x_2)$, and noise variance σ_n^2:

$$y_* = K(X_*, X)[K(X, X) + \sigma_n^2 I]^{-1} y,$$

$$\mathrm{cov}(y_*) = K(X_*, X_*) - K(X_*, X)[K(X, X) + \sigma_n^2 I]^{-1} K(X, X_*)$$

(Requires solution of large symmetric systems of equations)

Prediction problem

- Learning about parameters of covariance function and σ_n^2 by maximising log-likelihood:

$$\log p(y|X) \propto -\frac{1}{2} y^{\mathrm{T}} [K(X,X) + \sigma_n^2 I]^{-1} y - \frac{1}{2} \log |K(X,X) + \sigma_n^2 I|$$

(Evaluation also requires eigenvalues of large symmetric matrix)

- Exploit structure of data (gridded) and structure of covariance function (separable) to decompose matrices as tensor matrix products … then, e.g., combine with iterative methods to solve equations

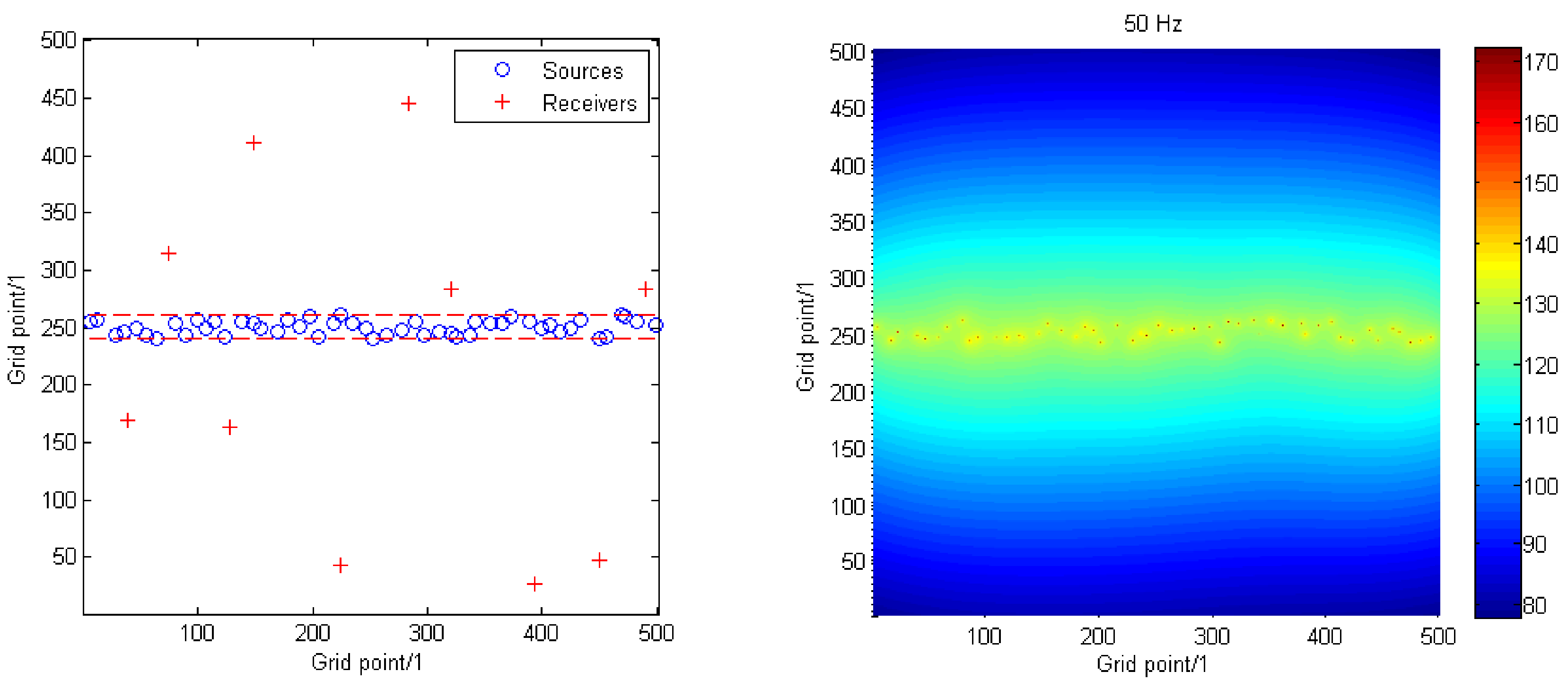
  (Copes with large problems but computations are slow)

Source identification and tracking problem

National Physical Laboratory

- Add knowledge that the measured quantity depends on a small number of sources and a model for how the quantity varies with distance from a source

  (For an acoustic problem, this could be a model of propagation loss)



Source identification and tracking problem

- For a single time instant, vector s represents source factors at possible source locations (within shipping lane)

- Find solution $s \geq 0$ to minimize

$$||As - y||_2^2 + \tau||s||_1$$

First term matches model to sensor observations y: highly under-determined system: maybe ~100 observations but ~10,000 unknowns

Second term regularises solution by forcing sparsity

Parameter τ used to control balance between “fitting” data and level of sparsity

Columns of design matrix A are highly coherent, which limits the “spatial resolution” to which the source locations can be estimated

Source identification and tracking problem

- Account for additional knowledge that locations of some of the sources are known (from GPS transponder data), but not their source levels

- Use knowledge of the precision of the sensors to provide uncertainty evaluation

  (LASSO → Bayesian LASSO?)

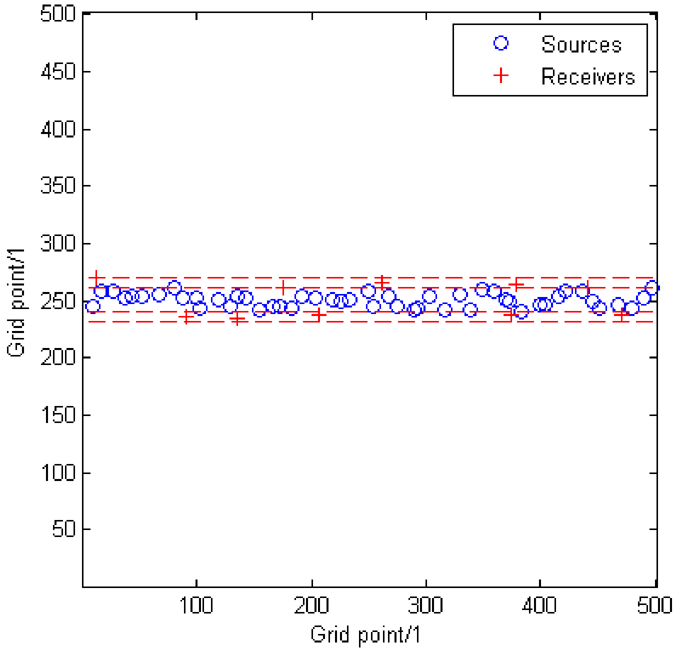
- Use data recorded at consecutive times to track sources

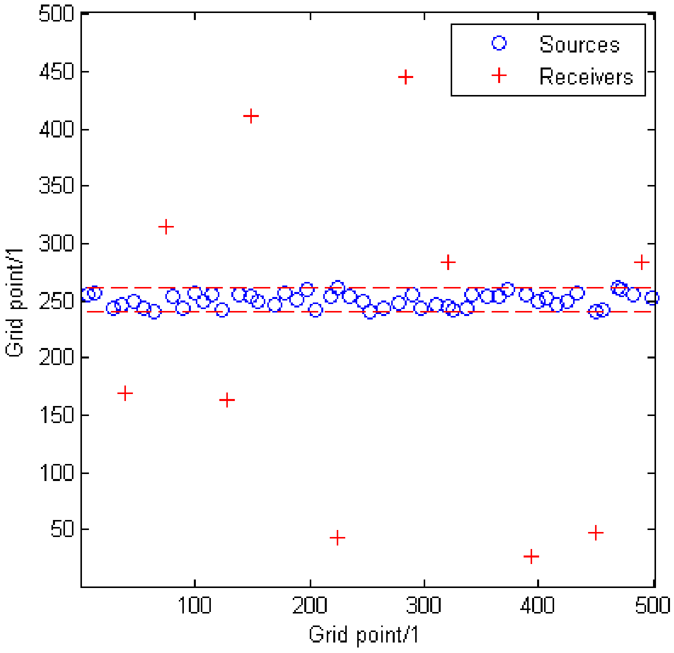
  (The sources can be expected to move along continuous paths … initially straight-lines … and to have a constant source level)

  (“Real-time” solution in the form of a “filter”?)

Design problem

- To deploy a sensor network, need to decide
  - Number of sensors
  - Locations of sensors
  - “Quality of sensors”: short-term (noise characteristics) and long-term (drift characteristics)





Design problem

- Optimise a measure of information (gain)
  - E.g., trace of covariance matrix for predictions made at a number of spatial locations
- But balanced against constraints
  - On cost (dependent on number and quality of sensors)
  - On where the sensors may be located (e.g., shipping lane is inaccessible)
- May also be a design specification
  - Requirement to make a prediction that meets a target uncertainty

Data

- Real airborne acoustic sensor network data

  (~15 sensors measuring at ~30 frequencies every minute for seven days – some data is missing – possibility of providing data for much longer period)

- Simulated underwater acoustic sensor network data

  (Investigating possibility of accessing real data measured in the Baltic Sea – but a propagation loss function would be needed)

- Air quality sensor network data

  (Possibility of accessing data from networks run by NPL – some low resolution [daily] ozone concentration data recorded over a number of years at a number of sites across the UK is available)

NPL
National Physical Laboratory

Department for
Business, Energy
& Industrial Strategy

FUNDED BY BEIS

The National Physical Laboratory is operated by NPL Management Ltd, a wholly-owned company of the Department for Business, Energy and Industrial Strategy BEIS).