Meteorology and neural networks

Weather it is good or not

Richard Lan, Dónal Scanlan, Viktor Tengnäs
Weather agenda

- History and climate modelling
- Numerical weather prediction
- Neural networks
- Hybrid models
- Future and conclusion

Note: We will be using the Mattias Wahde method of keeping you updated on the presentation agenda
A brief history of weather

- Fascination since ancient times
- Rituals to control the weather
- Basic instruments invented between the 15th and 18th century
- Weather forecasting networks during the 19th century
  - Telegraph
A brief history of weather

- Establishment of weather organisations motivated by need for storm forecasts in the late 1800’s
- Much criticism of early approaches
- European forecasting dwarfed in scale and budget by US counterpart
- Norway 1918: developed new forecasting theories based on three-dimensional interactions between cold and warm fronts
A brief history of weather

- Lorentz in 1961, weather prediction → chaos theory
- Sensitivity to initial conditions
- “Does the flap of a butterfly’s wings in Brazil set off a tornado in Texas?” -Philip Merilees
- Tiros 1 (first meteorological satellite) enters orbit in 1960
Modelling

○ Atmosphere as a fluid
  - Continuity equation
  - Navier-Stokes
  - Thermal energy equation
  - Ideal gas law

○ Time developments for wind speeds, density, pressure and temperature

○ Modern models account for further interactions
Weather agenda

✓ History and climate modelling
  ● Numerical weather prediction
  ● Neural networks
  ● Hybrid models
  ● Future and conclusion
Numerical Weather Prediction

- Type of forecasting we are most familiar with
- Conditions at next time step calculated using:
  - Previous conditions
  - Deterministic mathematical models
- The earth, its atmosphere and oceans are divided into a grid with varying resolution
- Short term prediction
- Long term prediction (ensemble methods)
Meteorologic example: yr.no

- AROME (short-term)
- ECMWF (long-term)
- Fix predictions with empirical data (temperature variation)
- Have considered neural networks
AROME

- **Application of Research to Operations at Mesoscale**
- Fine Resolution - c. 1.3 km
- 48 hours prediction
- 15 countries in Europe
  - Each country has adapted the model to its specific weather conditions
- **Combination of:**
  - Méso-NH model (non-hydrostatic mesoscale model)
  - IFS/Arpège software (global integrated forecasting system)
  - Aladin (regional version of Arpège) model
- Ensemble model being developed
Ensemble Methods

An ensemble of:
- Different forecasting models
- Different parameters
- Different initial conditions
  (analyses)
Hurricane Sandy
Example: ECMWF-IFS

- European Centre for Medium-Range Weather Forecast’s Integrated Forecasting System founded 1975: 18 cooperating states
- Medium range (up to 2 weeks, delivered to members 2 x day) & extended range (up to 1 year)
- Ensemble of 51 forecasts (different initial conditions and physical parameters)
- 32/64 km resolution, 91 layers
Weather agenda

✓ History and climate modelling
✓ Numerical weather prediction
- Neural networks
- Hybrid models
- Future and conclusion
houses and buildings and destroyed some
Example of neural at work

The backpropagation model:

- Input layer: one node per dimension and time step
- Hidden layer: nodes fully interconnected with input layer
- Output layer: one node per dimension
- Dimensions:
  - Pressure
  - Temperature
  - etc.
Capabilities of neural networks

- Weather data is irregular and non-linear
- Analysis of gathered data to make predictions → obscure structural trends found
- Practical to modify prediction “model” (example: expand dimensions of data)
- Predictions for a single dimension, e.g. precipitation, work well
Limitations of neural networks

- Can be iterated for prediction of more time steps, but training and power
- Also inaccurate over a longer period of time
- Untrained situations & risk of overfitting
- Blindness to the laws of nature
Ensemble of Neural Networks

● Similar idea to standard numerical ensemble methods

● Saskatchewan, Canada (Maqsood et al, 2004)
  ○ Used several, different neural networks: ERNN, HFM, MLPN, RBFN
  ○ In addition: regression techniques
  ○ Take a weighted average of their predictions
  ○ Dynamically updated weights of each model (certainties)
  ○ Empirically: RBFN generally more reliable than HFM

● Same restrictions apply however, but performance is improved
Weather agenda

✓ History and climate modelling
✓ Numerical weather prediction
✓ Neural networks
  ● Hybrid models
  ● Future and conclusion
Hybrid model (Grover et al. 2015)

**Goal:** A neural network model that respects spatiotemporal dependencies among weather dimensions induced by atmospheric physics

1. Identify and learn from recurring weather patterns over time
2. Produce predictions that are spatially coherent
3. Capture interdependencies between weather dimensions

**Dimensions:** Wind velocity (x & y), pressure, temperature and dew point (humidity)

**Note:** Surface-level prediction
Components of the hybrid model

1. Individual predictors
2. Spatial interpolation
3. Joint modelling of weather dimensions

Different kinds of neural networks
1. Individual predictors

- **Used to:** Provide insights about the weather at particular locations
  - Gradual change over time
  - Cyclicity through the seasons
- **Method:** Ensemble of boosted decision-tree learners
  - Common method for data mining
- **Trained using historical data**
- **Different predictors needed for each weather station**
2. Spatial interpolation

- **Used to:** Obtain weather predictions between the individual predictors
- **Method:** Radial basis functions and Gaussian processes
- Captures similarity among data points that are close in space and time
- Respects physical constraints among the weather dimensions
2. **Spatial interpolation**

- Static Field: Without physical constraints
- Hybrid Field: With physical constraints
3. Joint modelling of weather dimensions

- **Used to**: Capture the interactions between weather dimensions
- **Method**: Deep belief network of stacked Restricted Boltzmann Machines
  - Learns a probability distribution over its set of inputs
- **Based on laws of thermodynamics**
- **Find interaction between dimensions statistically**
Weather agenda

✓ History and climate modelling
✓ Numerical weather prediction
✓ Neural networks
✓ Hybrid models

● Future and conclusion
The Future

Finer resolution, more data, faster processing

- atmospheric sensors on airplanes, cars
- nano-satellites
- crowd-sourcing data collection: PressureNET, Dark Sky, & WeatherSignal
  - e.g. Galaxy S4 - temperature, pressure, light intensity, magnetic flux and humidity
  - more suitable for ‘nowcasting’
The Future

- Probability weather forecasts based on ensembles - Probcast

- Lack of basic statistical understanding

- What effect will climate change have on forecasting?
Conclusions

- Climate is chaotic
- The main method of the past decades: numerical methods
- Recent advancements: neural networks and machine learning
- Hybrid models in the future?
- More data, greater computational power → higher resolution
Thanks for listening!
Discussion Questions

■ Who is responsible if false predictions are made? What is the public responsibility in terms of interpreting the statistics?
■ Weather predictions will never be perfect but to what degree of accuracy is attainable and/or sufficient in terms of optimising complexity using presented methods?
■ Knowing that our climate is changing relatively rapidly, to what level can we rely on historical data for training neural networks?