Bigelow | Laboratory for Ocean Sciences

Ocean Forecasting

Introduction

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Forecasting

"Tell us what the future holds, so we may know that you are gods."

- An ancient source

Hyndman, R.J., & Athanasopoulos, G. (2021) Forecasting: principles and practice, 3rd edition, OTexts: Melbourne, Australia. OTexts.com/fpp3.

Key Concepts

Terminology

- Prediction
- Projection
- Forecast
- Foresight
- "Foreshape”

*Definitions change somewhat depending on what field you’re in

Terminology

Prediction -

- Very generally, an if-then statement tied to a scientific hypothesis
- Not limited to the future (e.g. could make a prediction about data)

Terminology

Projection -

- Evaluation of future states of a system in response to changes in driving forces / under different scenarios
- Assumptions concerning future socioeconomic and technological developments that may or may not be realized and are therefore subject to substantial uncertainty

Luo et al. (2011) Ecological forecasting and data assimilation in a data-rich era. Ecological Applications, 21(5) 1429–1442

Terminology

Forecast -

- Predicting some future event or condition usually as a result of study and analysis, along with uncertainty
- Forecasting requires both broad and expert knowledge and is often model based

Dietze, M.C., Fox, A., Beck-Johnson, L.M., Betancourt, J.L., Hooten, M.B., Jarnevich, C.S., Keitt, T.H., Kenney, M.A., Laney, C.M., Larsen, L.G., et al. (2018). Iterative near-term ecological forecasting: Needs, opportunities, and challenges. Proc. Natl. Acad. Sci. USA 115, 1424–1432.

Payne, M.R., Hobday, A.J., MacKenzie, B.R., Tommasi, D., Dempsey, D.P., Fässler, S.M.M., Haynie, A.C., Ji, R., Liu, G., Lynch, P.D., et al. (2017). Lessons from the first generation of marine ecological forecasts. Front. Mar. Sci. https://doi.org/10.3389/fmars.2017.00289.

Terminology

Foresight -

- Systematically attempting to look into the longer-term future of science, technology, the economy, and society with the aim of identifying the areas of strategic research and the emerging of generic technologies likely to yield the greatest economic and social benefits
- Imagine different futures and their consequences and, on that basis, to engage in informed decision making.
- Foresight rests on two key assumptions: (1) that the future is not laid out and (2) that decisions made and action taken today can affect the future

Martin, B.R. (1995). Foresight in science and technology. Technology Analysis & Strategic Management 7, 139–168.

Andersen, A.D., and Andersen, P.D. (2017). Foresight for inclusive devel- opment. Technol. Forecast. Soc. Change 119, 227–236.

Hobday et al. (2020) Quantitative Foresighting as a Means of Improving Anticipatory Scientific Capacity and Strategic Planning. One Earth 3, 631–644 https://doi.org/10.1016/j.oneear.2020.10.015

Terminology

Foreshape -

- Make a forecast, projection, or foresight of an event with the explicit aim of shaping the outcome of the event
- **Reflexivity**: a prediction changing the outcome of what it predicts

Record, N.R.; Pershing, A.J. Facing the Forecaster's Dilemma: Reflexivity in Ocean System Forecasting. Oceans 2021, 2, 738-751. https://doi.org/10.3390/oceans2040042

Terminology

- Model
- Algorithm

Terminology

Algorithm Accountability

- The principle that an algorithmic system should employ a variety of controls to ensure the operator can verify it acts in accordance with its intentions, as well as identify and rectify harmful outcomes
- Institutions should be held responsible for the results of their programmed algorithms

https://www2.datainnovation.org/2018-algorithmic-accountability.pdf

https://datasociety.net/wp-content/uploads/2019/09/DandS_Algorithmic_Accountability.pdf

Makridakis Competitions

M-Competition findings:

- Statistically sophisticated or complex methods do not necessarily provide more accurate forecasts than simpler ones.
- The relative ranking of the performance of the various methods varies according to the accuracy measure being used.
- The accuracy when various methods are combined outperforms, on average, the individual methods being combined and does very well in comparison to other methods.
- The accuracy of the various methods depends on the length of the forecasting horizon involved.

https://en.wikipedia.org/wiki/Makridakis_Competitions

Makridakis Competitions

M-4, 2018:

- Artificial Intelligence (Machine Learning, ML), as well as traditional statistical ones
- The conclusion … is that the accuracy of individual statistical or ML methods is low and that hybrid approaches and combination of methods is the way forward in order to improve forecasting accuracy and make forecasting more valuable.

https://robjhyndman.com/hyndsight/m4comp/

Historical Background of Ocean Forecasting

History

Components of an ocean forecast

- Prediction involving the ocean environment (physical, biological, chemical, social)
- Mathematical and computer algorithms
- Two-way human-environment interactions

History

650 - 300 BCE

- Around 650 BCE., the Babylonians tried to predict short-term weather changes based on the appearance of clouds and optical phenomena such as haloes.
- By 300 BCE, Chinese astronomers had developed a calendar that divided the year into 24 festivals, each festival associated with a different type of weather.

https://earthobservatory.nasa.gov/features/WxForecasting/wx2.php

History

300 BCE - Theophrastus

- Book of Signs
- *“If many jelly fish appear in the sea this is a sign of a stormy season.”*

History

800s - Muhammad ibn Musa al-Khwarizmi

- Namesake of the word “algorithm”
- Head of the library of the House of Wisdom in Baghdad

History

1800s - Augusta Ada King, Countess of Lovelace

- First computer programmer
- Wrote the first computer algorithm

History

1800s - Eunice Newton Foote

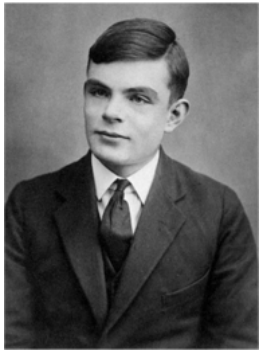
- Greenhouse effect (CO_2 warms atmosphere)
- Campaigned for women's rights

History

1900s - Kantorovich

- Linear programming optimization
- Forecasting how many cars could move across ice to supply Leningrad during WWII

History



1900s - Alan Turing

- Machine learning & artificial intelligence
- “Turing Test”

History

2000s - Daniel Pauly

- Human impacts significant enough to alter the on global ocean
- Shifting baselines: our frame of reference changes with time

Open questions

Open questions

- What are the limits of predictability?
  - What factors shape those limits?
  - Does predictability decrease with increasing forecast horizon?

Lewis AS, Rollinson CR, Allyn AJ, Ashander J, Brodie S, Brookson CB, Collins E, Dietze MC, Gallinat AS, Juvigny-Khenafou N, Koren G, McGlinn DJ, Moustahfid H, Peters JA, Record NR, Robbins CJ, Tonkin J, Wardle GM (2022) The power of forecasts to advance ecological theory. *Methods in Ecology and Evolution*. https://doi.org/10.1111/2041-210X.13955

Open questions

- How does predictability depend on the component of the system?
  - Levels of biological organization? E.g. species vs community.
  - Biological-physical coupling?

Lewis AS, Rollinson CR, Allyn AJ, Ashander J, Brodie S, Brookson CB, Collins E, Dietze MC, Gallinat AS, Juvigny-Khenafou N, Koren G, McGlinn DJ, Moustahfid H, Peters JA, Record NR, Robbins CJ, Tonkin J, Wardle GM (2022) The power of forecasts to advance ecological theory. *Methods in Ecology and Evolution*. https://doi.org/10.1111/2041-210X.13955

Open questions

- What are the dominant types of uncertainty?
  - Initial conditions
  - Parameter uncertainty
  - Process uncertainty
  - Is there stabilizing feedback in the system?

Open questions

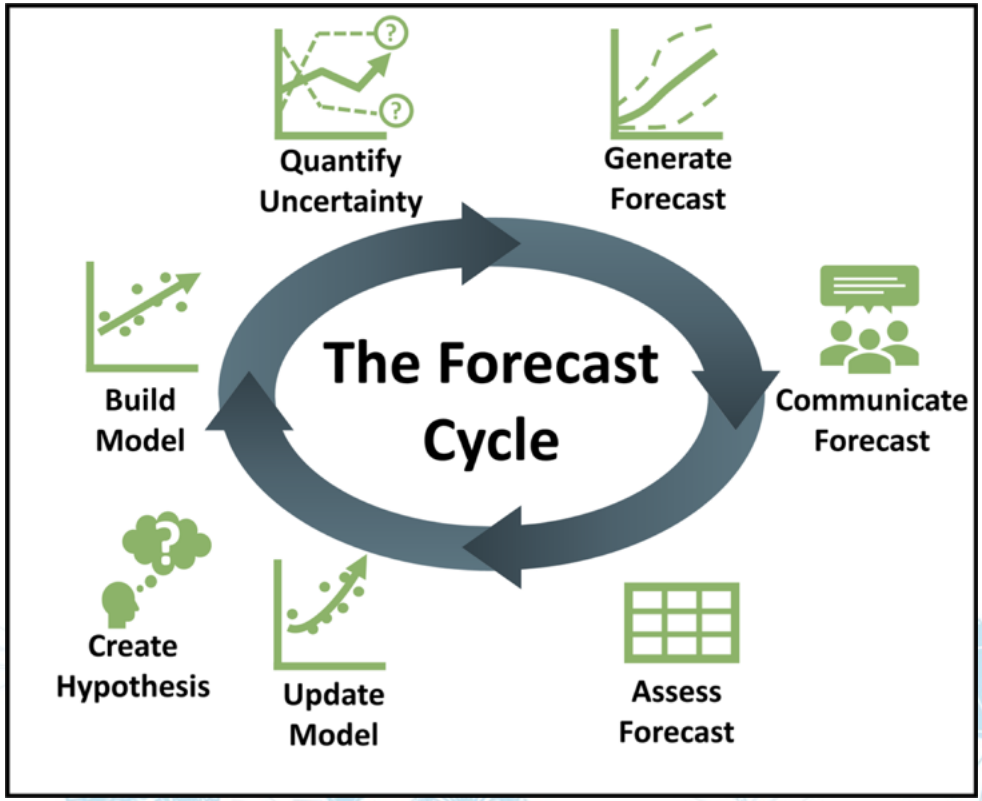
- How does the forecast influence the outcome?
  - Self-fulfilling prediction
  - Self-defeating prediction

Open questions

- Should we forecast?
  - When is it / is it not ethical to forecast?

Frameworks

Forecast Cycle



EDDIE materials
https://serc.carleton.edu/eddie/teaching_materials/modules/module5.html

Technology Readiness Levels

	NOAA TRL	HAB EWS TRL
1	Basic Research	Background/basic understanding of phenomenon of concern Local/traditional knowledge
2	Applied Research	Stakeholder involvement Identification of user needs / concerns
3	Proof of Concept	Monitoring, data analysis Demonstrated predictive relationships
4	Validation of system in a test environment	Hindcast exercise of prediction
5	Validation of system in relevant environment	Hindcast analysis of full EWS system Stakeholder feedback
6	Demonstration in a test environment	Running in operational mode privately
7	Demonstration in a relevant environment	Running in operational mode with focus group Stakeholder feedback
8	Demonstration in the actual environment	Running in operational mode with larger user community Stakeholder feedback
9	Deployment and regular use	Deployment with sustained support and maintenance

Joint FAO, IOC, IAEA document