

# Modeling and Analysis of Time Series Data

## Chapter 10: Forecasting

Edward L. Ionides

# Outline

- 1 Introduction
- 2 ARIMA forecasting
- 3 Prophet
- 4 Forecasting vs modeling

# Model-based forecasts

- Data,  $y_{1:N}^*$ , and a model  $Y_{1:N+h}$  with joint density  $f_{Y_{1:N+h}}(y_{1:N+h}|\theta)$  can be used to **forecast** future values  $y_{N+1:N+h}$  up to a **horizon**,  $h$ .
- A model-based **probabilistic forecast** of the not-yet-observed values  $y_{N+1:N+h}$  is

$$f_{Y_{N+1:N+h}|Y_{1:N}}(y_{N+1:N+h}|y_{1:N}^*; \hat{\theta}), \quad (1)$$

where  $\hat{\theta}$  is a point estimate such as an MLE.

- A model-based **point forecast** of  $y_{N+1:N+h}$  is

$$\mathbb{E}[Y_{N+1:N+h}|Y_{1:N} = y_{1:N}^*; \hat{\theta}]. \quad (2)$$

- Point forecasts and probabilistic forecasts have many applications in business and elsewhere.

# Evaluating forecasts

- Point forecasts could be evaluated by squared error, absolute error, relative squared error, relative absolute error, etc.
- Probabilistic forecasts are naturally evaluated by the forecast log-density,

$$\log f_{Y_{N+1:N+h}|Y_{1:N}}(y_{N+1:N+h}|y_{1:N}^*; \hat{\theta}), \quad (3)$$

evaluated at the data,  $y_{N+1:N+h}^*$ , once it is collected.

- Due to time dependence, and limited amounts of data, it can be problematic to evaluate by cross-validation.
- Note that log-likelihood can be written as a sum of one-step forecast log-densities:

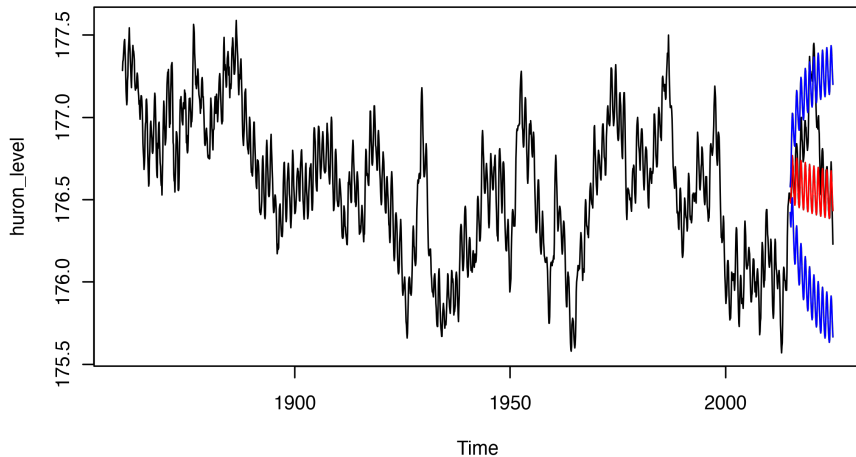
$$\log f_{Y_{1:N}}(y_{1:N}^*; \theta) = \sum_{n=1}^N \log f_{Y_n|Y_{1:n-1}}(y_n^*|Y_{1:n-1}^*; \theta) \quad (4)$$

# ARIMA forecasting

`predict.Arima()` computes the conditional Gaussian distribution for forecasting an ARIMA model.

```
dat <- read.table(file="huron_level.csv", sep=",", header=TRUE)
huron_level <- ts(as.vector(t(dat[,2:13])), start=1860, freq=12)
time <- rep(dat$Year, each=12) + rep(0:11, nrow(dat))/12
huron_old <- window(huron_level, end=2014.99)
sarma <- arima(huron_old, order=c(1,0,1),
  seasonal=list(order=c(1,0,1), period=12))
f.sarma <- predict(sarma, n.ahead=120)
f.val <- as.vector(f.sarma$pred)
f.se <- as.vector(f.sarma$se)
f.time <- as.vector(time(f.sarma$pred))
plot(huron_level)
lines(f.time, f.val, col="red")
lines(f.time, f.val+1.96*f.se, col="blue")
lines(f.time, f.val-1.96*f.se, col="blue")
```

# 95% prediction interval from December 2014



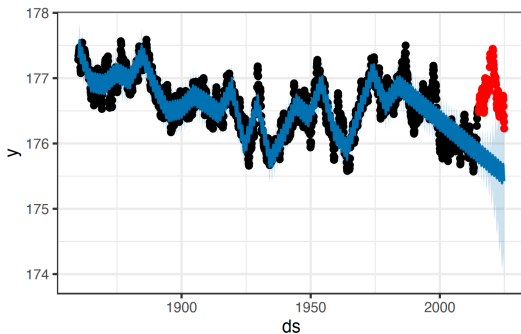
# Facebook Prophet

- ARIMA models are good for relatively short time series.
- SARIMA is good for monthly and quarterly data, but less so for daily or hourly.
- You may have already experienced this. Large-scale forecasting competitions confirm it (Makridakis *et al.*, 2020).
- Prophet was designed for high-frequency (daily, hourly) business forecasting tasks at Facebook, and is widely used for similar tasks elsewhere.
- Prophet does penalized regression estimating trend and seasonality components. It can also do Bayesian fitting.
- Unlike ARIMA, Prophet cannot describe general covariance structures.

```

library(prophet)
library(ggplot2)
history <- data.frame(y = huron_old,
  ds = seq(as.Date('1860-01-01'), as.Date('2014-12-01'), by = 'm'))
fit <- prophet(history)
future <- make_future_dataframe(fit, periods = 10*12,freq='month')
forecast <- predict(fit,future)
plot(fit,forecast)+
  geom_point(data=data.frame(ds=future$ds[-(1:1860)]),y=huron_level[

```





# Forecasting versus model fitting

- A good model should imply a good model-based forecast.
- Long-term forecasting is extrapolation. The model may be unreliable far from the timeframe used to build it.
- Without evidence to support a model for long-term forecasts, uncertainty estimates should be high. Uncertainty estimates are also uncertain!
- Deep learning methods need large amounts of data. They are not yet standard for forecasting. Prophet uses automatic differentiation techniques that enable deep learning.

# Forecasting with trends and covariates

- A model with trends and covariates must project those into the future in order to forecast.
- Uncertainty about future trends may be captured by “stochastic trend” models. Prophet does this.
- We’ve seen the difficulty assessing stationarity vs slowly varying trend. The same issue arises with forecasting. How do we know if a trend will continue, or if it will change in future?

## Further reading

- Section 3.5 of Shumway and Stoffer (2017) covers ARIMA forecasting.
- Hyndman and Khandakar (2008) introduces the forecast R package.
- Taylor and Letham (2018) presents the Facebook Prophet forecasting algorithm.

# References and Acknowledgements

- Hyndman RJ, Khandakar Y (2008). “Automatic time series forecasting: The forecast package for R.” *Journal of Statistical Software*, **27**, 1–22.
- Makridakis S, Spiliotis E, Assimakopoulos V (2020). “The M4 Competition: 100,000 time series and 61 forecasting methods.” *International Journal of Forecasting*, **36**(1), 54–74.
- Shumway RH, Stoffer DS (2017). *Time Series Analysis and its Applications: With R Examples*. 4th edition. Springer.
- Taylor SJ, Letham B (2018). “Forecasting at scale.” *The American Statistician*, **72**(1), 37–45.
- Compiled on February 24, 2025 using R version 4.4.2.

# References and Acknowledgements II

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