

Approaches to Modeling, Types of uncertainty

Ecological Forecasting, Jan 26th

First, checking in on lab from
Tuesday.

Any questions, or issues?

Revisiting logistic growth

$$N_{t+1} = N_t + rN_t(1 - N_t/K)$$

The diagram shows the logistic growth equation $N_{t+1} = N_t + rN_t(1 - N_t/K)$. Two blue arrows point from labels to specific terms in the equation: one arrow points to the term rN_t with the label "Low density growth rate", and another arrow points to the term N_t/K with the label "Carrying Capacity".

Forward Modeling

$$N_{t+1} = N_t + rN_t(1 - N_t/K)$$

Estimated

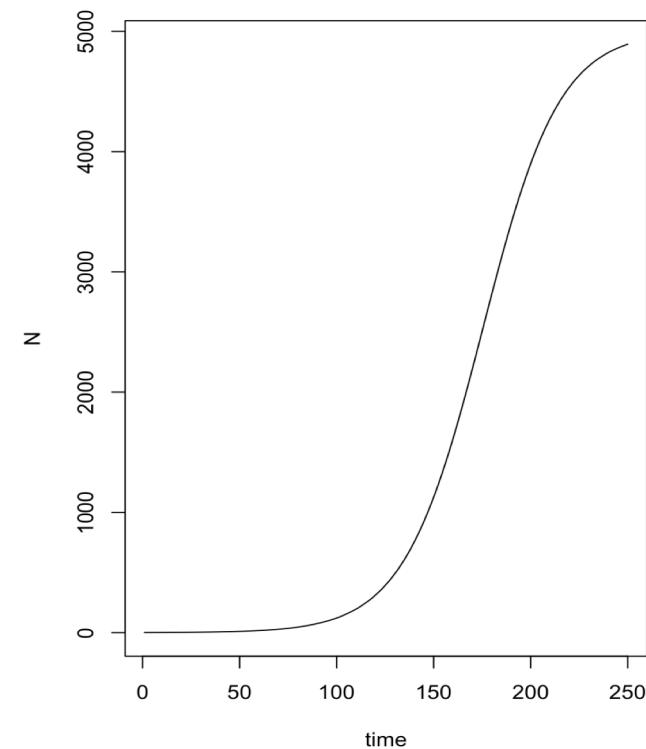
Data

Data

Forward Modeling

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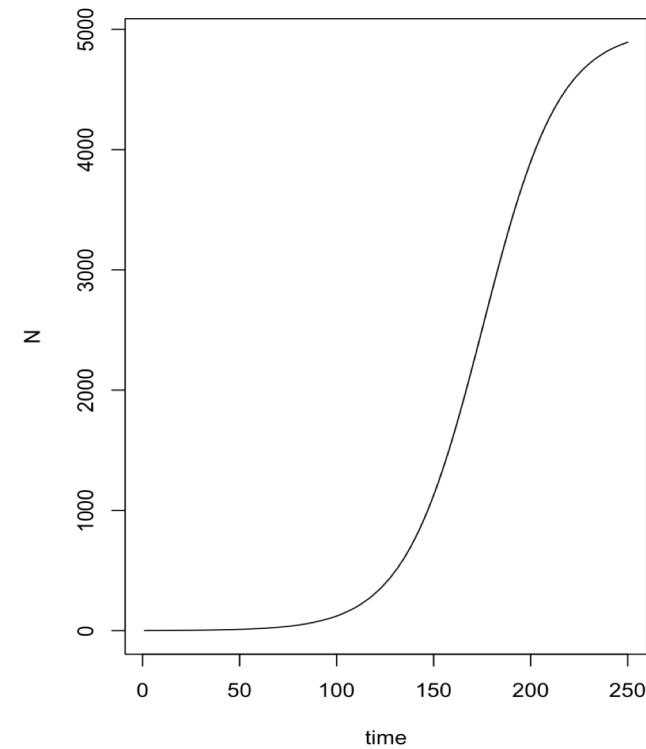
Model is purely deterministic,
stochasticity can be added in some forms



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Parameter	Quantity	Units
<i>Aboveground state variables</i>		
$n(\mathbf{z}, \mathbf{x}, a, t)$	density [†] of size \mathbf{z} type \mathbf{x} plants in gaps of age a at time t	m^{-2}
$p(a, t)$	distribution of gap ages a at time t	dimensionless
<i>State dimensions</i>		
\mathbf{z}	plant size $\mathbf{z} = [z_x, z_a] = [B_s, B_g]$	$\text{kg C}, \text{kg C}$
\mathbf{x}	plant type $[x_1, x_2] \cdot x_1 = 0$ if C_3 , 1 if C_4 , $x_2 = \text{leaf longevity}$	dimensionless, yr
a	gap age	yr
t	time	yr
<i>Plant resource environment</i>		
\mathbf{r}	resource vector $\mathbf{r} = [\phi, W, N]$	$\text{J} \cdot \text{m}^{-2} \cdot \text{s}^{-1}, \text{m}^3 \text{H}_2\text{O}/\text{m}^2, \text{kg N}/\text{m}^2$
ϕ	photosynthetically active radiation (PAR)	$\text{J} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$
W	soil water content	$\text{m}^3 \text{H}_2\text{O}/\text{m}^2$
N	plant available soil nitrogen content	$\text{kg N}/\text{m}^2$
<i>Transition rates</i>		
\dot{g}_s	structural biomass growth rate	$\text{kg C}/\text{yr}$
\dot{g}_a	living biomass tissue growth rate	$\text{kg C}/\text{yr}$
μ	mortality rate	yr^{-1}
f	fecundity	yr^{-1}
λ	total disturbance rate $\lambda = \lambda_F + \lambda_{DI}$	yr^{-1}
λ_F	fire frequency	yr^{-1}
λ_{DI}	rate of canopy gap formation	yr^{-1}
s	survivorship of plants following disturbance	dimensionless
<i>Plant size characteristics</i>		
h	height	m
B_s	living biomass ($B_s + B_g + B_{sw}$)	kg C
B_s	structural stem biomass	kg C
B_l	leaf biomass	kg C
B_r	root biomass	kg C
B_{sw}	sapwood biomass	kg C
<i>Leaf-level carbon and water fluxes</i>		
A_n	net rate of carbon gain per unit leaf area	$\mu\text{mol C} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$
Ψ	evapotranspiration rate per unit leaf area	$\mu\text{mol H}_2\text{O} \cdot \text{m}^{-2} \cdot \text{yr}^{-1}$
<i>Decomposition model state variables and coefficients</i>		
C_1	fast soil carbon pool	$\text{kg C}/\text{m}^2$
C_2	structural soil carbon pool	$\text{kg C}/\text{m}^2$
N_1	fast soil nitrogen pool	$\text{kg N}/\text{m}^2$
N_2	structural soil nitrogen pool	$\text{kg N}/\text{m}^2$
<i>Miscellaneous</i>		
$n_0(\mathbf{z}, \mathbf{x}, a)$	initial plant density $n(\mathbf{z}, \mathbf{x}, a, 0)$ [‡]	m^{-2}
$p_0(a)$	initial gap age distribution	dimensionless
\mathbf{z}_0	seedling size	$\text{kg C}, \text{kg C}$
y	integer gap number (1.. Q)	dimensionless
h^*	height above which mortality is treated as disturbance	m
c_s	stomatal conductance	$\mu\text{mol H}_2\text{O} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$
T_L	leaf temperature	$^\circ\text{C}$
T_A	atmospheric air temperature	$^\circ\text{C}$
C_i	interstitial concentration of CO_2	mol/mol
C_a	atmospheric concentration of CO_2	mol/mol

[†] $n(\mathbf{z}, \mathbf{x}, a, t)$ is technically a density distribution where $n(\mathbf{z}, \mathbf{x}, a, t)dz_dx_da$ is the per m^{-2} density of type \mathbf{x} plants between size z_s and $z_s + dz_s$, and size z_a and $z_a + dz_a$ in gaps aged between a and $a + da$ at time t .

Paul Moorecroft, Ecosystem Demography model

Forward Modeling

Anyone know of any applications of forward modeling?

Forward modeling, historically, has been of the most common modeling approaches. Big push to make more and more complex forward models came in the 1970s, 1980s with increases in computing power.

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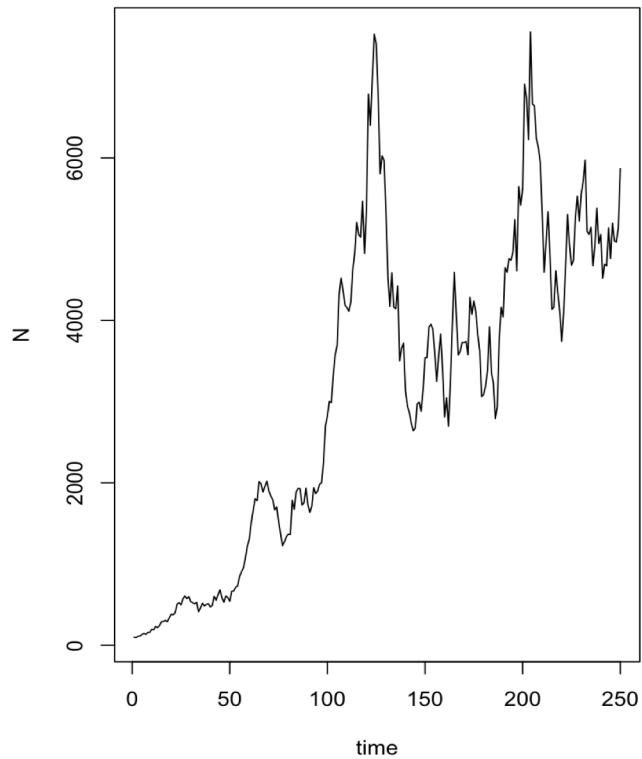
While computers are powerful and important tools, adding additional processes and complexity to models does not always yield better predictions.

Inverse modeling

$$N_{t+1} = N_t + rN_t(1 - N_t/K)$$

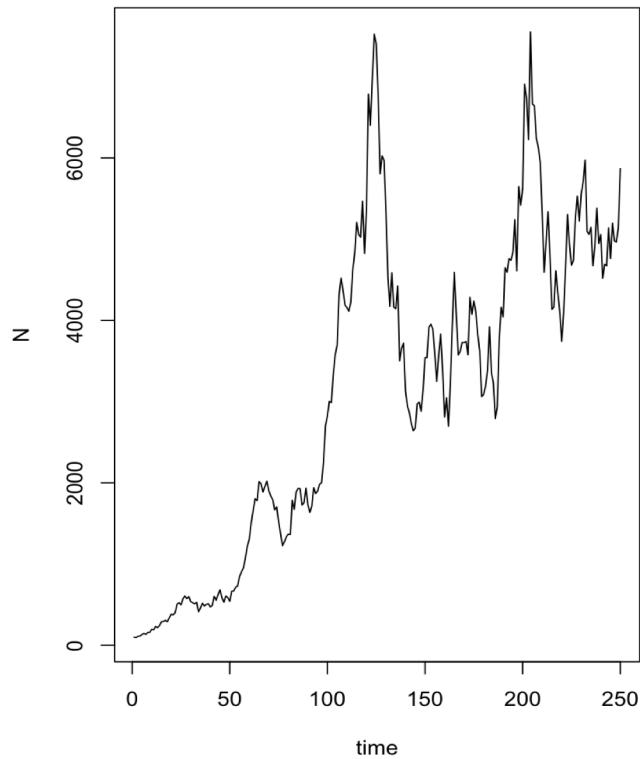
The equation $N_{t+1} = N_t + rN_t(1 - N_t/K)$ is displayed. Three blue arrows point upwards from the text below to specific terms in the equation: one arrow points to N_t from the word "Data", another arrow points to rN_t from the word "Estimated", and a third arrow points to N_t/K from the word "Estimated".

Inverse Modeling



$$N_{t+1} = N_t + rN_t(1 - N_t/K)$$

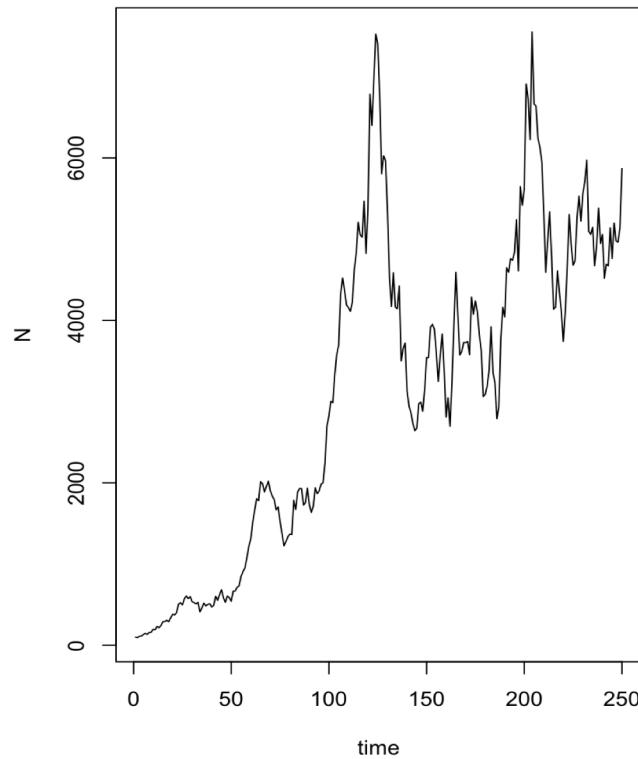
Inverse Modeling



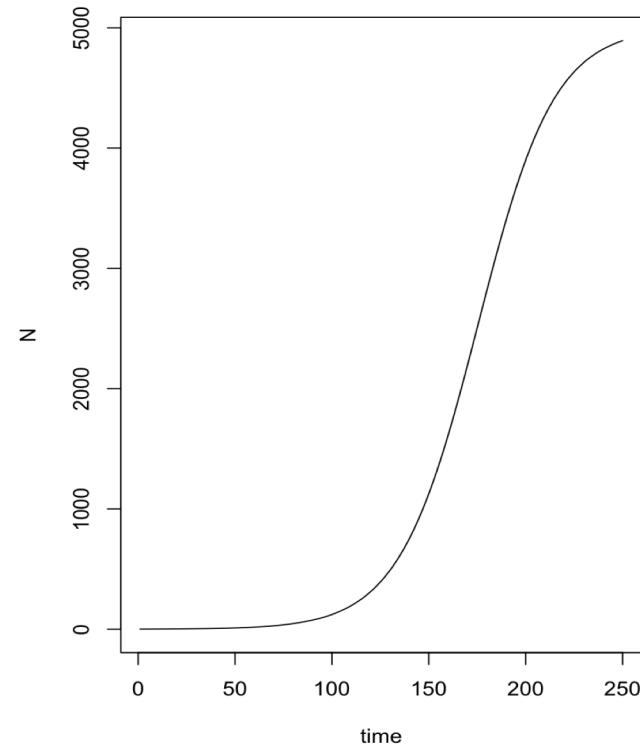
Probability distributions describes
connection between data and model

$$N_{t+1} = N_t + rN_t(1 - N_t/K)$$

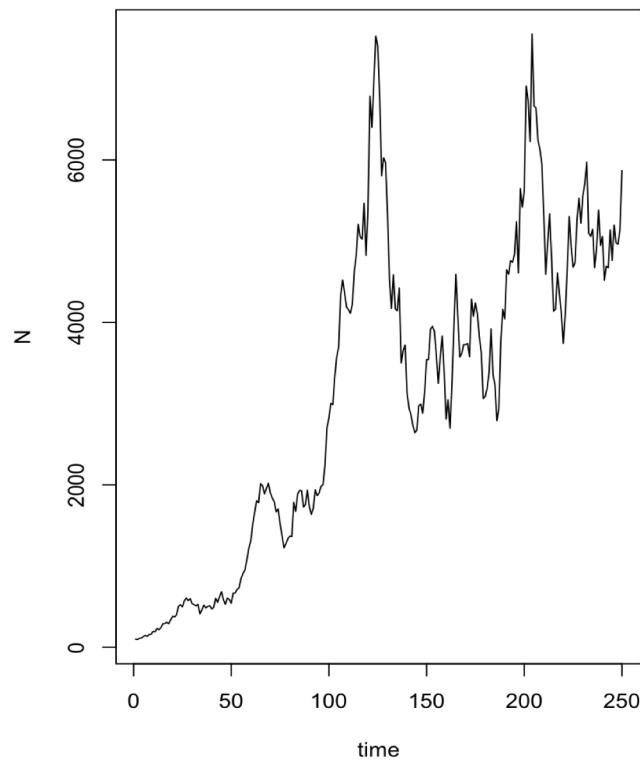
Forward and Inverse don't match



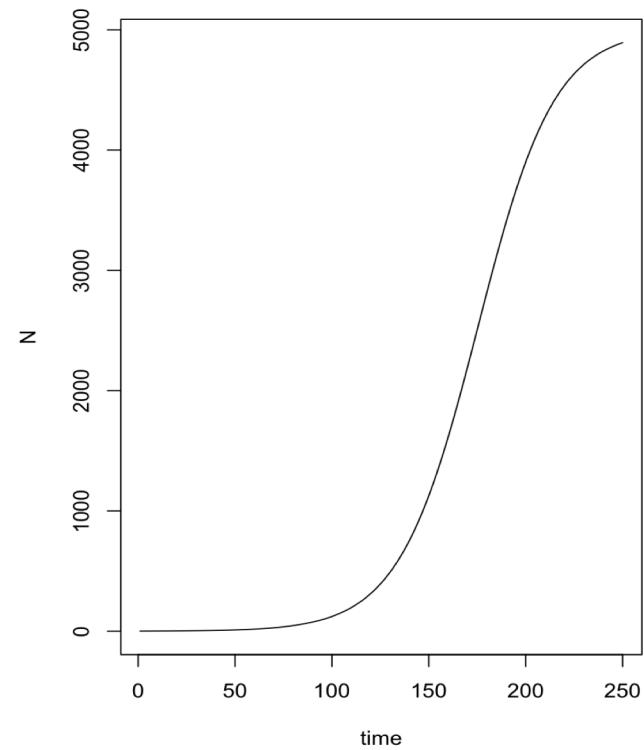
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What accounts for this?



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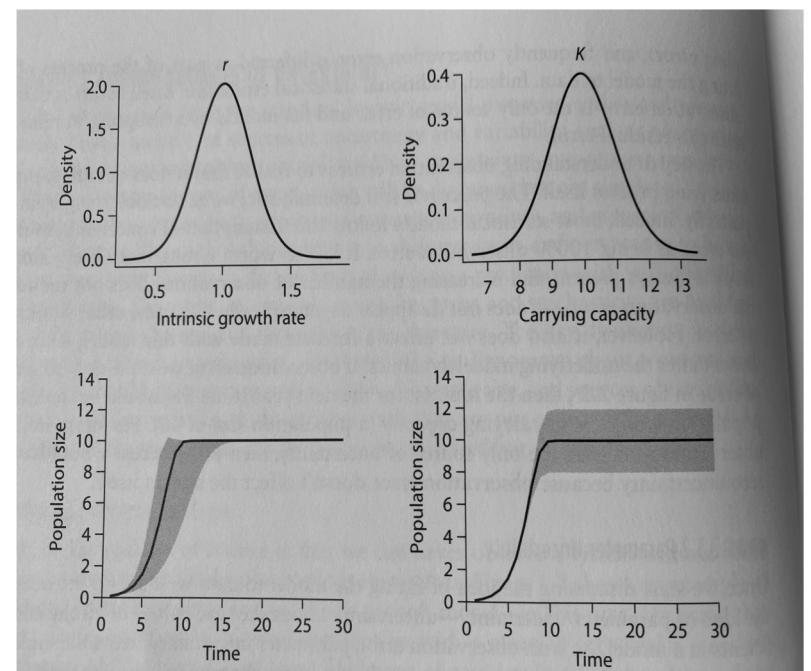
Variability and uncertainty

Types of variability and uncertainty

Parameter uncertainty: The true values of the parameter in the models are unknown

This type of uncertainty can be accounted for by both forward and inverse modeling approaches

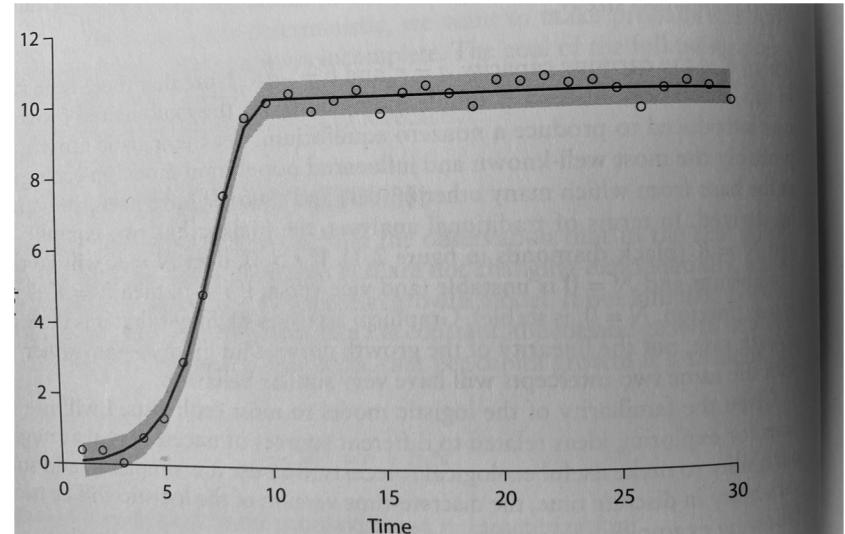
Parameter uncertainty will be reduced with more data collection.



Types of variability and uncertainty

Observation uncertainty: The true state of the system can not be observed without error.

If observation error is the only source of error then the underlying forecast is deterministic.



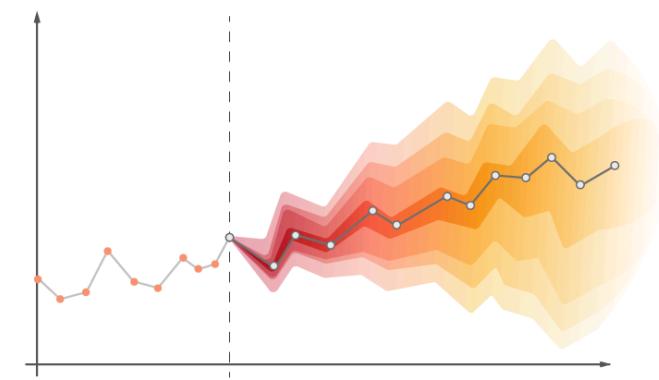
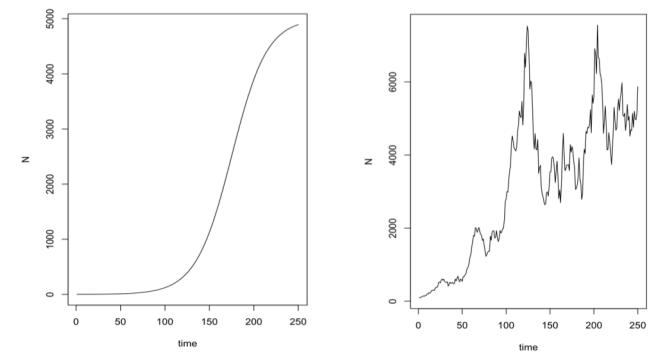
Types of variability and uncertainty

Process error/variability: Our models do not include all of the relevant processes.

This source of error is very common in ecology and environmental sciences, but hard to include/describe with forward modeling approaches.

One way is using a model ensembling.

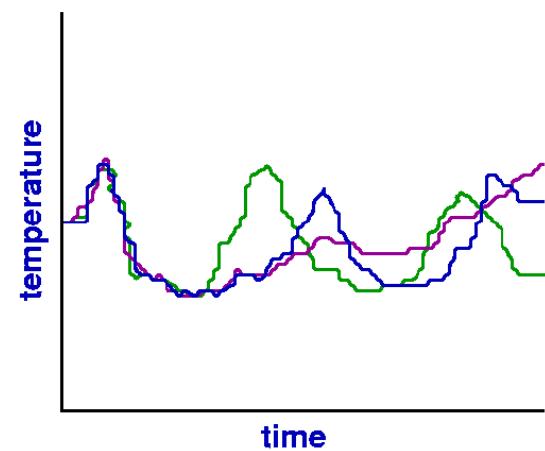
Because process error is uncertainty about the true state of a system, it propagates out in forecasts, often leading to greater uncertainty as time/space goes on.



Types of variability and uncertainty

Initial condition uncertainty: Not knowing the current state of the system.

This is most important in chaotic systems like weather.



Grab bag of other uncertainties

Driver uncertainty: If forecast includes “drivers” like temperature, than uncertainty in the forecast of that driver propagate through to forecasts. One of the reasons why the most ecologically realistic model may not be the best for forecasting.

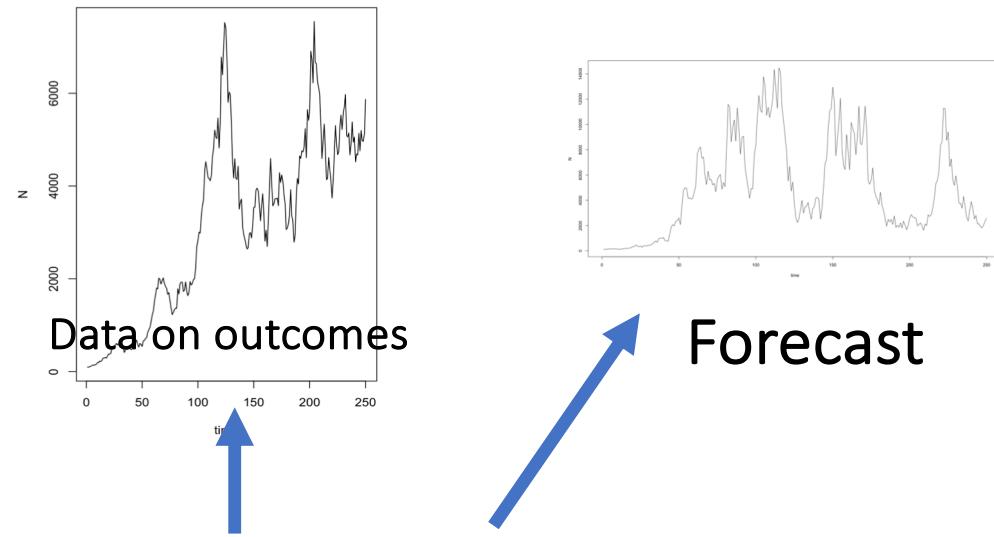
Numerical approximation: Computers make approximation errors. This rarely matters for most of our applications, but good to be aware of.

So how do we build models and forecasts
in the face of all of these sources of
uncertainty?

Models as scaffolds

We use models to describe the relationship (or covariance) between different sources of data, and data yet to be observed.

Models as scaffolds



Data on outcomes

Forecast

time

$$N_{t+1} = N_t + rN_t(1 - N_t/K)$$



Data on parameters

Soapbox

Models are sometimes described as process-based, mechanistic, statistical, phenomenological.

What does that mean?

Soapbox

Any (or at least most) useful
models contain some
element of all of these.

Readings- Clark et al.

What does “inherent uncertainty” mean and what are some examples?

What are some of the problems if a forecast doesn’t handle uncertainty properly?

What is the “bet-hedging” described in the paper and can you think of any examples?

What is your impression of how the “next steps” discussed here have been implemented in the last 20 years?

Readings-Houlihan et al.

What is model transferability?

What is bias-variance tradeoff? How does it impact prediction?

Can we truly falsify forecast (in the NHT sense)?

Next week!

Beginning some analysis of simple timeseries data.

Fitting and forecasting timeseries using R functions.