

# Lecture 5: Predictions and variance



University of  
St Andrews

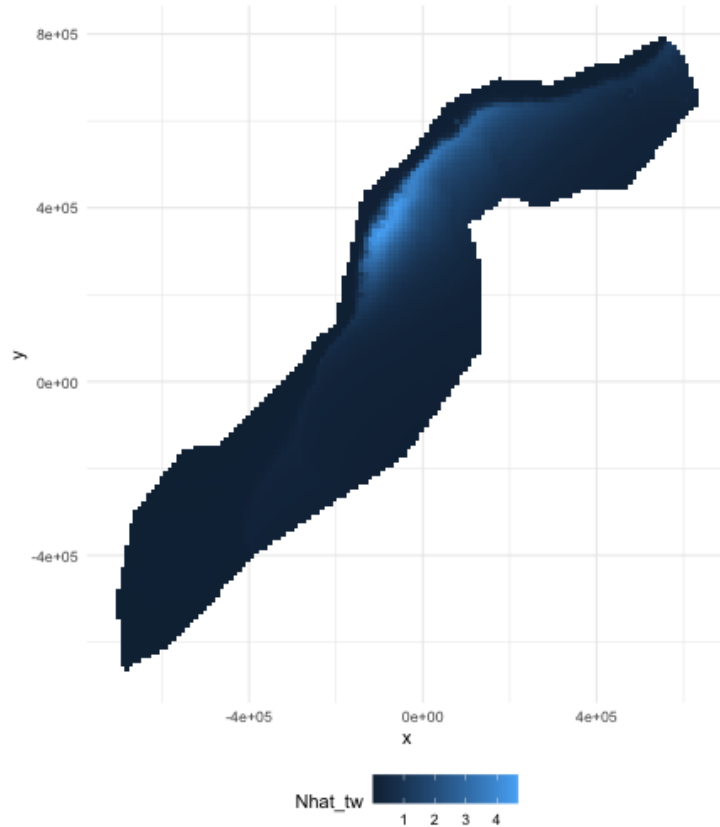
# So far...

- Build, check & select *detection* models
- Build, check & select *spatial* models

**What about predictions?**

Let's talk about maps

# What does a map mean?



- Grids!
- Cells are abundance estimate
- "snapshot"
- Sum cells to get abundance
- Sum a subset?

# Going back to the formula

Count model (  $j$  observations):

$$n_j = A_j \hat{p}_j \exp[\beta_0 + s(y_j) + s(\text{Depth}_j)] + \epsilon_j$$

# Going back to the formula

Count model (  $j$  observations):

$$n_j = A_j \hat{p}_j \exp[\beta_0 + s(y_j) + s(\text{Depth}_j)] + \epsilon_j$$

Predictions (index  $r$ ):

$$\hat{n}_r = A_r \exp[\hat{\beta}_0 + \hat{s}(y_r) + \hat{s}(\text{Depth}_r)]$$

Need to "fill-in" values for  $A_r$ ,  $y_r$  and  $\text{Depth}_r$ .

# Predicting

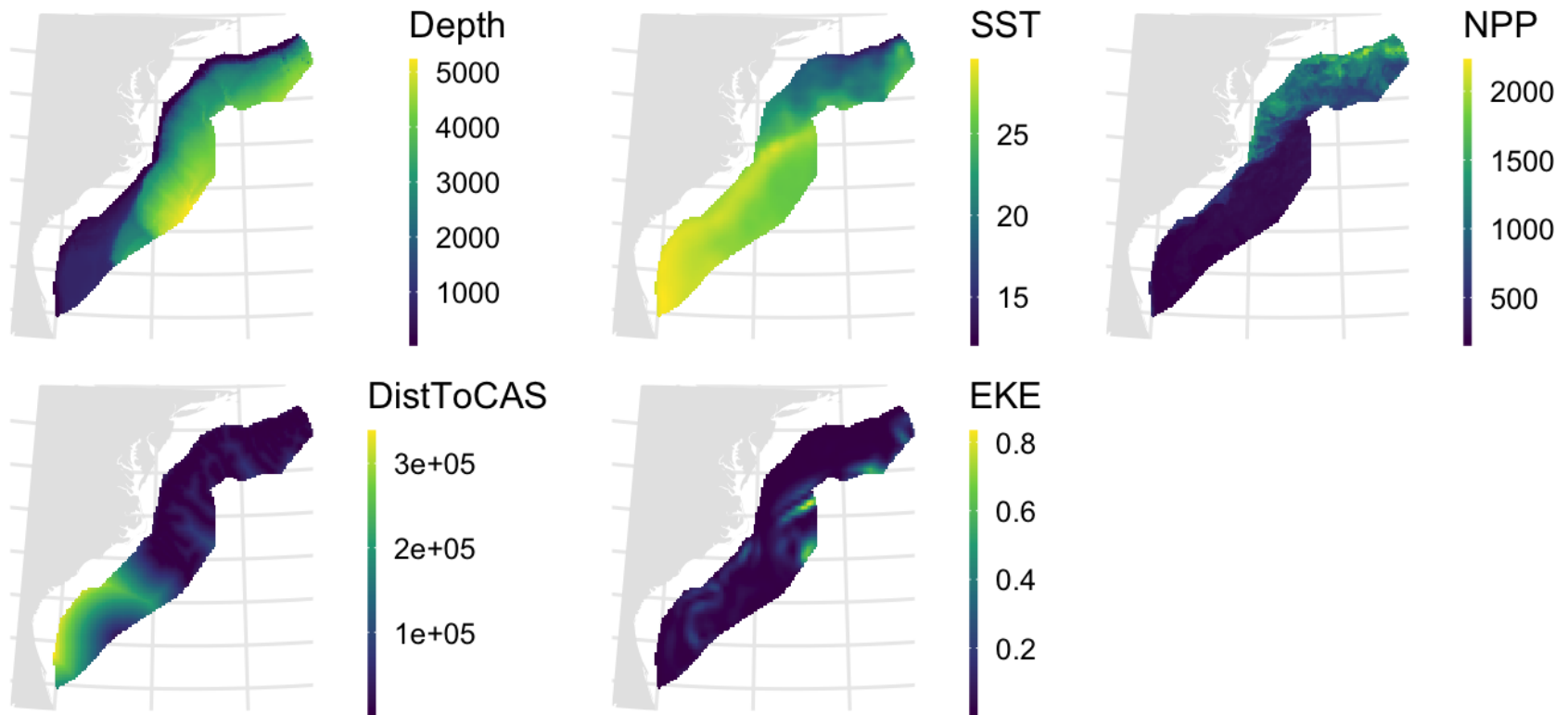
- With these values can use `predict` in R
- `predict(model, newdata=data, off.set=off.set)`
- `off.set` gives the area of the grid cells
- more info in `?predict.dsm`

# Prediction data

##		x	y	Depth	SST	NPP	DistToCAS
##	126	547984.6	788254	153.59825	12.04609	1462.521	11788.974
##	127	557984.6	788254	552.31067	12.81379	1465.410	5697.248
##	258	527984.6	778254	96.81992	12.90251	1429.432	13722.626
##	259	537984.6	778254	138.23763	13.21393	1424.862	9720.671
##	260	547984.6	778254	505.14386	13.75655	1379.351	8018.690
##	261	557984.6	778254	1317.59521	14.42525	1348.544	3775.462
##		EKE off.set		long	lat		
##	126	0.0008329031	1e+08	-66.52252	40.94697		
##	127	0.0009806611	1e+08	-66.40464	40.94121		
##	258	0.0011575423	1e+08	-66.76551	40.86781		
##	259	0.0013417297	1e+08	-66.64772	40.86227		
##	260	0.0026881567	1e+08	-66.52996	40.85662		
##	261	0.0045683752	1e+08	-66.41221	40.85087		



# Predictors

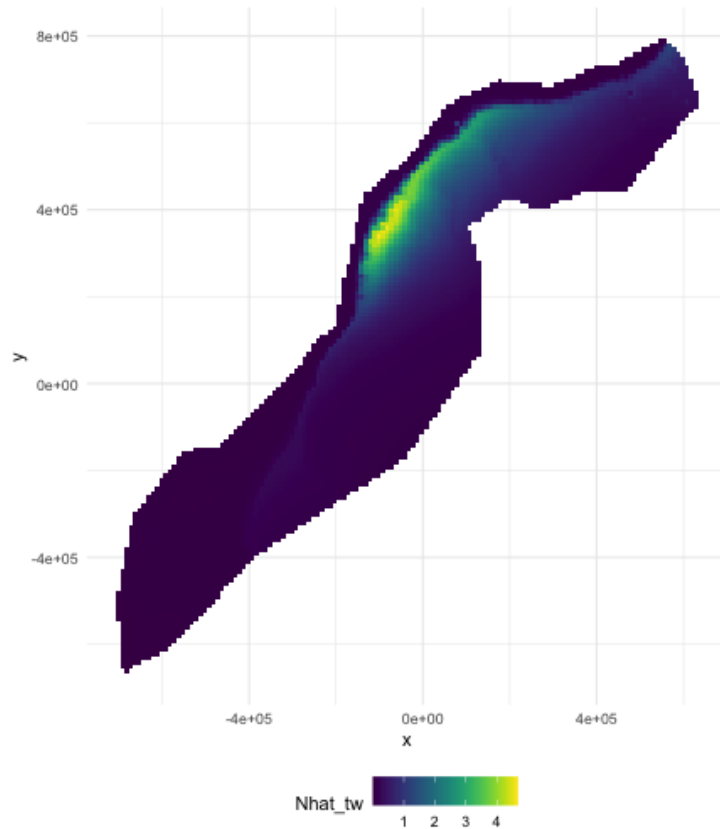


# Making a prediction

- Add another column to the prediction data
- Plotting then easier (in R)

```
predgrid$Nhat_tw <- predict(dsm_all_tw_rm,  
                           predgrid,  
                           off.set=predgrid$off.set)
```

# Maps of predictions



```
p <- ggplot(predgrid) +  
  geom_tile(aes(x=x, y=y,  
                fill=Nhat_tw))  
  scale_fill_viridis() +  
  coord_equal()  
print(p)
```

# Total abundance

Each cell has an abundance, sum to get total

```
sum(predgrid$Nhat_tw)
```

```
## [1] 2491.863
```

# Subsetting

R subsetting lets you calculate "interesting" estimates:

```
# how many sperm whales at depths shallower than 2500m?  
sum(predgrid$Nhat_tw[predgrid$Depth < 2500])
```

```
## [1] 1006.27
```

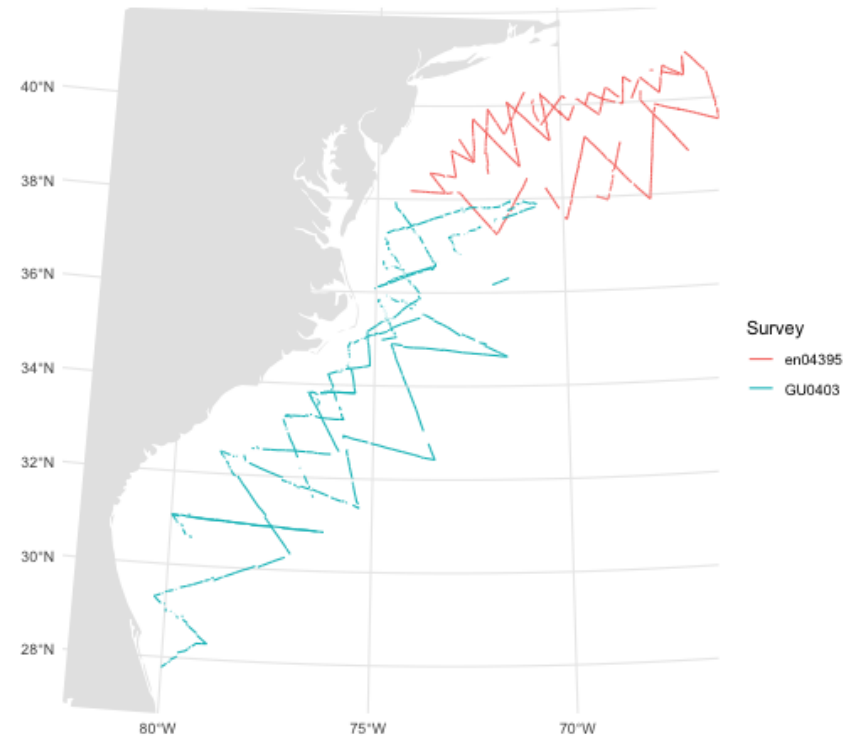
```
# how many sperm whales East of 0?  
sum(predgrid$Nhat_tw[predgrid$x>0])
```

```
## [1] 1383.744
```

# Extrapolation

# What do we mean by extrapolation?

- Predicting at values outside those observed
- What does "outside" mean?
  - between transects?
  - outside "survey area"?



# Extrapolation

- In general, try not to do it!
- Variance issues?
- Space-time interchangeability?
- dsmextra package by Phil Bouchet
  - <https://densitymodelling.github.io/dsmextra/index.html>





# Prediction recap

- Using `predict`
- Getting "overall" abundance
- Subsetting
- Plotting in R
- Extrapolation (and its dangers)

# Estimating variance

Now we can make predictions

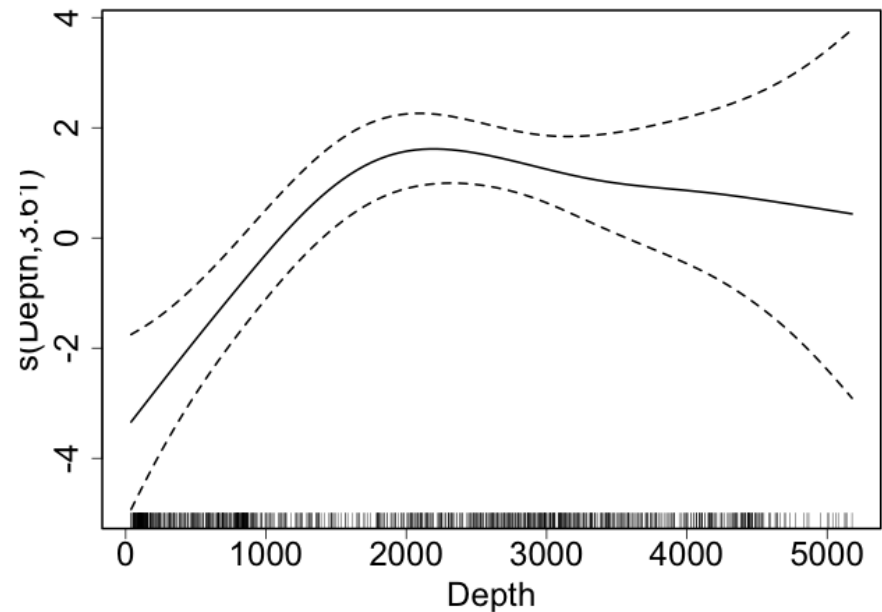
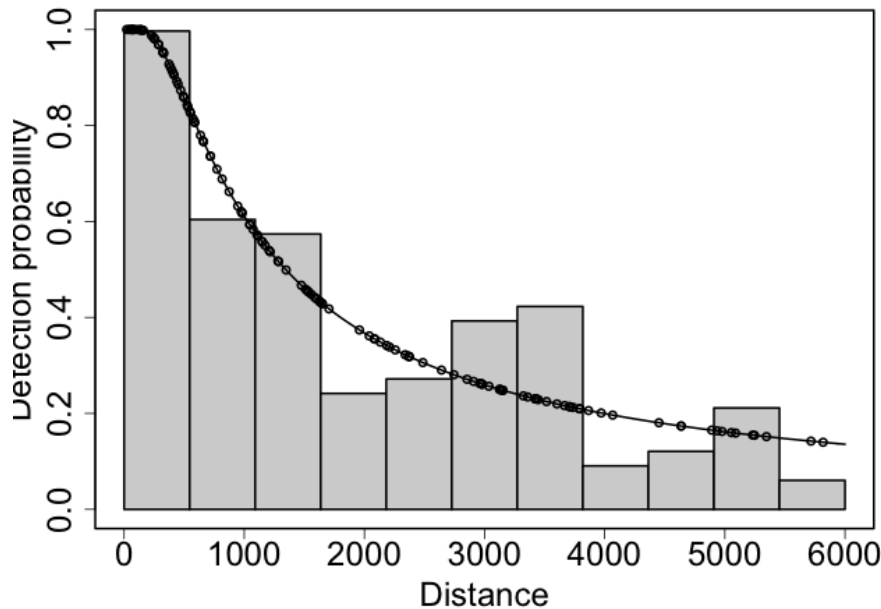
Now we are dangerous.

Predictions are useless without uncertainty

Where does uncertainty come from?

# Sources of uncertainty

- Detection function parameters
- GAM parameters
- (And more! But only looking at these 2 here!)



# Uncertainty of what?

- Uncertainty from detection function + GAM
- Want to talk about  $\hat{N}$ , so need to do some maths
- dsm does this for you!
- Details in Miller et al (2013) appendix

# GAM + detection function uncertainty

(Getting a little fast-and-loose with the mathematics)

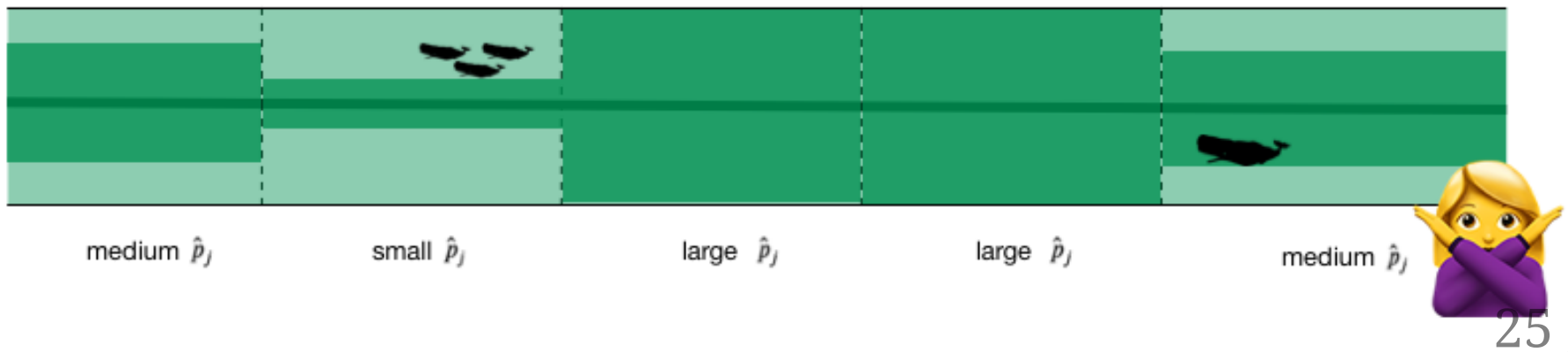
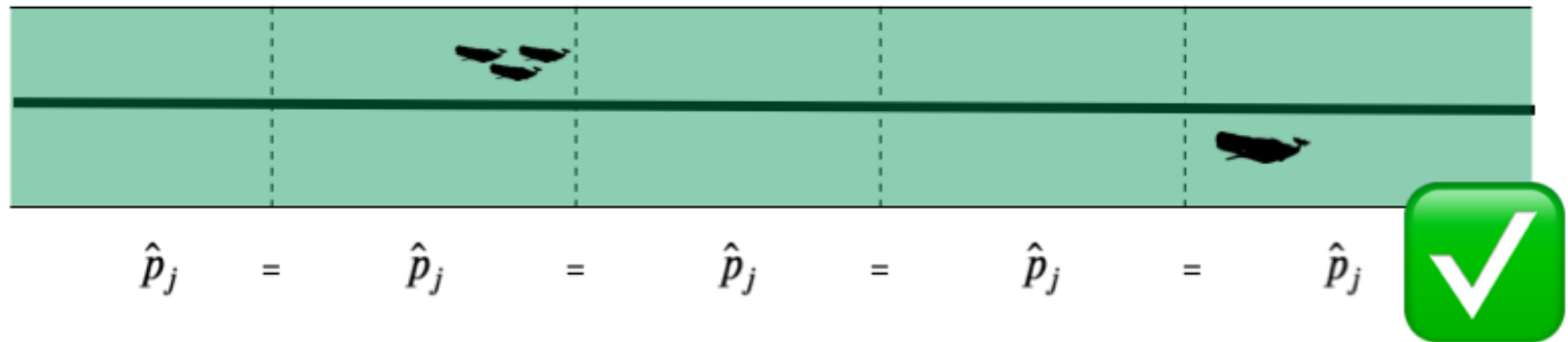
$$\text{CV}^2 (\hat{N}) \approx \text{CV}^2 (\text{GAM}) + \\ \text{CV}^2 (\text{detection function})$$

the "delta method"



# When can we use the delta method?

- Assumes detection function and GAM are **independent**
- This is okay if:
  - no detection function covariates



# Variance propagation

- When detection function is not independent
- Uncertainty "propagated" through the model
- Refit both models together
- Bravington, Miller and Hedley (2021)

# In R...

- Functions in `dsm` to do this
- `dsm.var.gam`
  - assumes spatial model and detection function are independent
- `dsm.var.prop`
  - propagates uncertainty from detection function to spatial model
  - only works for count models
  - covariates can only vary at segment level

# Variance of abundance

Using `dsm.var.gam`

```
dsm_tw_var_ind <- dsm.var.gam(dsm_all_tw_rm, predgrid,  
                             off.set=predgrid$off.set)  
summary(dsm_tw_var_ind)
```

```
## Summary of uncertainty in a density surface model calculated  
## analytically for GAM, with delta method  
##  
## Approximate asymptotic confidence interval:  
##      2.5%      Mean      97.5%  
## 1539.017 2491.863 4034.641  
## (Using log-Normal approximation)  
##  
## Point estimate           : 2491.863  
## CV of detection function : 0.2113123  
## CV from GAM              : 0.1329  
## Total standard error     : 622.0386  
## Total coefficient of variation : 0.2496
```

# Plotting - data processing

- Calculate uncertainty per-cell
- `dsm.var.*` thinks `predgrid` is one "region"
- Need to split data into cells (using `split()`)
- Need width and height of cells for plotting

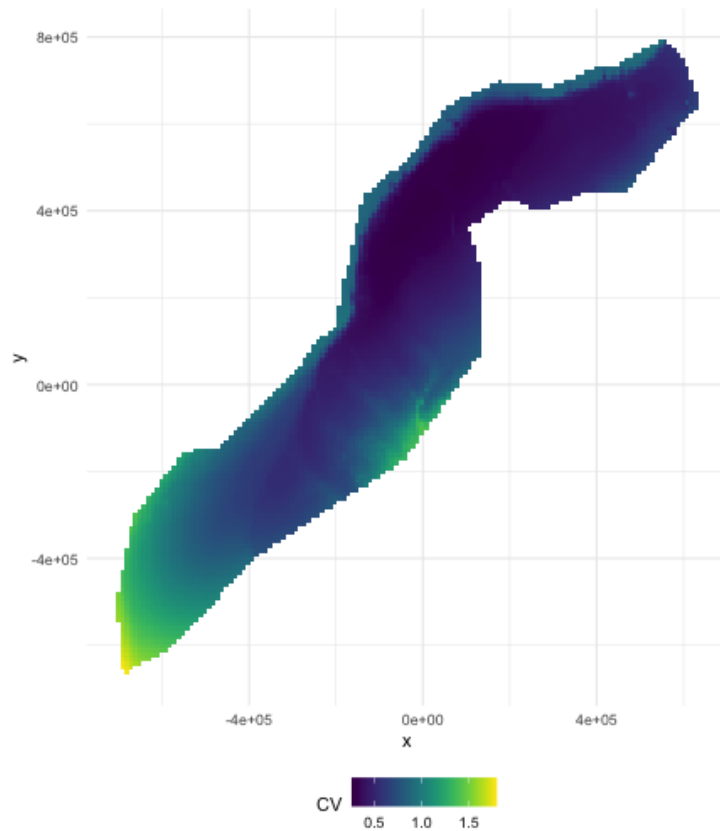
# Plotting (code)

```
predgrid$width <- predgrid$height <- 10*1000
predgrid_split <- split(predgrid, 1:nrow(predgrid))
head(predgrid_split,3)
```

```
## $`1`
##           x           y      Depth      SST      NPP DistToCAS
## 126 547984.6 788254 153.5983 12.04609 1462.521 11788.97
##           EKE off.set      long      lat      Nhat_tw
## 126 0.0008329031 1e+08 -66.52252 40.94697 0.01417646
##           height width
## 126 10000 10000
##
## $`2`
##           x           y      Depth      SST      NPP DistToCAS
## 127 557984.6 788254 552.3107 12.81379 1465.41 5697.248
##           EKE off.set      long      lat      Nhat_tw
## 127 0.0009806611 1e+08 -66.40464 40.94121 0.05123446
##           height width
## 127 10000 10000
##
## $`3`
##           x           y      Depth      SST      NPP DistToCAS
## 258 527984.6 778254 96.81992 12.90251 1429.432 13722.63
##           EKE off.set      long      lat      Nhat_tw
```

# CV plot

```
dsm_tw_var_map <- dsm.var.gam(dsm_all_tw_rm, predgrid_split,  
                             off.set=predgrid$off.set)
```



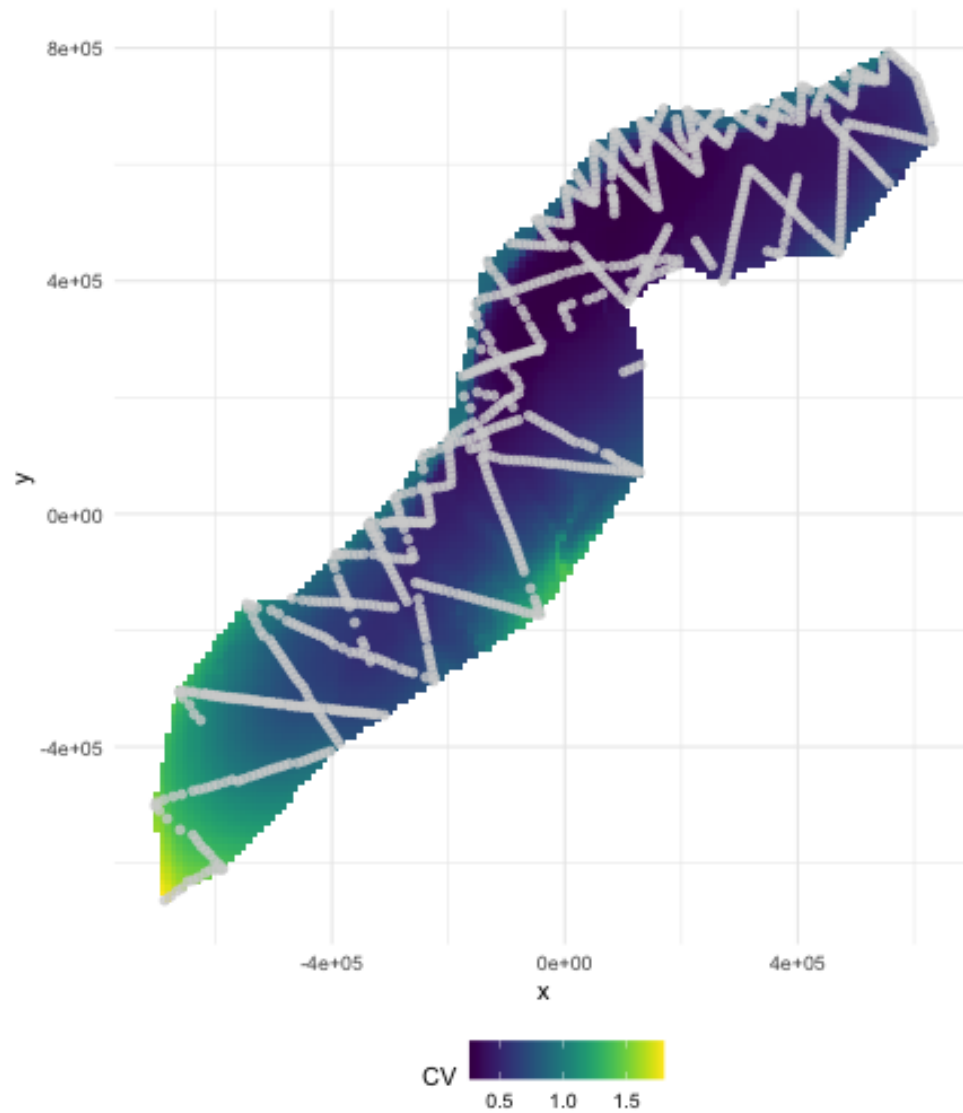
```
p <- plot(dsm_tw_var_map,  
          observations=FALSE,  
          plot=FALSE) +  
      coord_equal() +  
      scale_fill_viridis()  
print(p)
```

# Interpreting CV plots

- Plotting coefficient of variation
- Standardise standard deviation by mean
- $CV = se(\hat{N})/\hat{N}$  (per cell)
- Can be useful to overplot survey effort



# Effort overplotted



# Big CVs

- Here CVs are "well behaved"
- Not always the case (huge CVs possible)
- These can be a pain to plot
- Use `cut()` in R to make categorical variable
  - e.g. `c(seq(0,1, len=10), 2:4, Inf)` or `somesuch`
- (Example in practical)

# Uncertainty recap

- How does uncertainty arise in a DSM?
- Estimate variance of abundance estimate
- Map coefficient of variation

# Practical advice

# Pilot studies and "you get what you pay for"

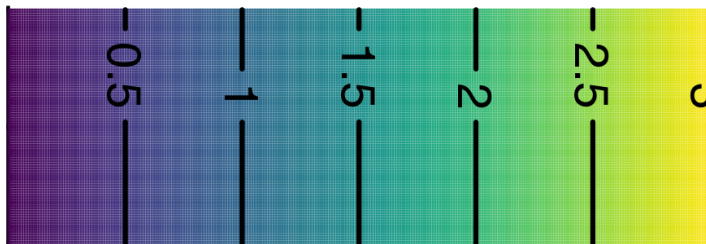
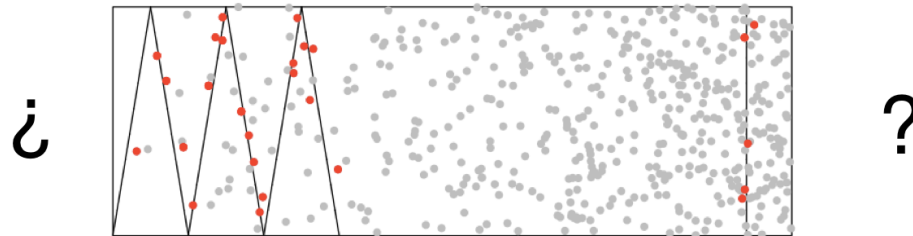
- Designing surveys is hard
- Designing surveys is essential
- Better to fail one season than fail for 5, 10 years
- Get information early, get it cheap
  - Inform design from a pilot study

# Avoiding rules of thumb

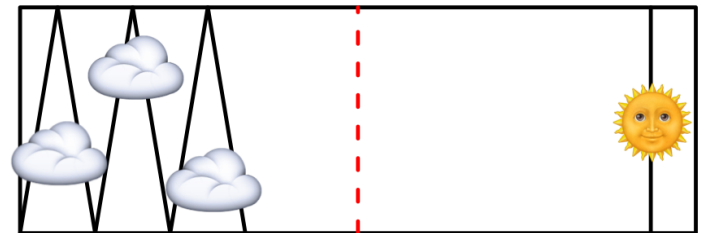
- Think about assumptions
  - Detection function
  - Spatial model
- Think about design
  - Spatial coverage
  - Covariate coverage

# Sometimes things are complicated

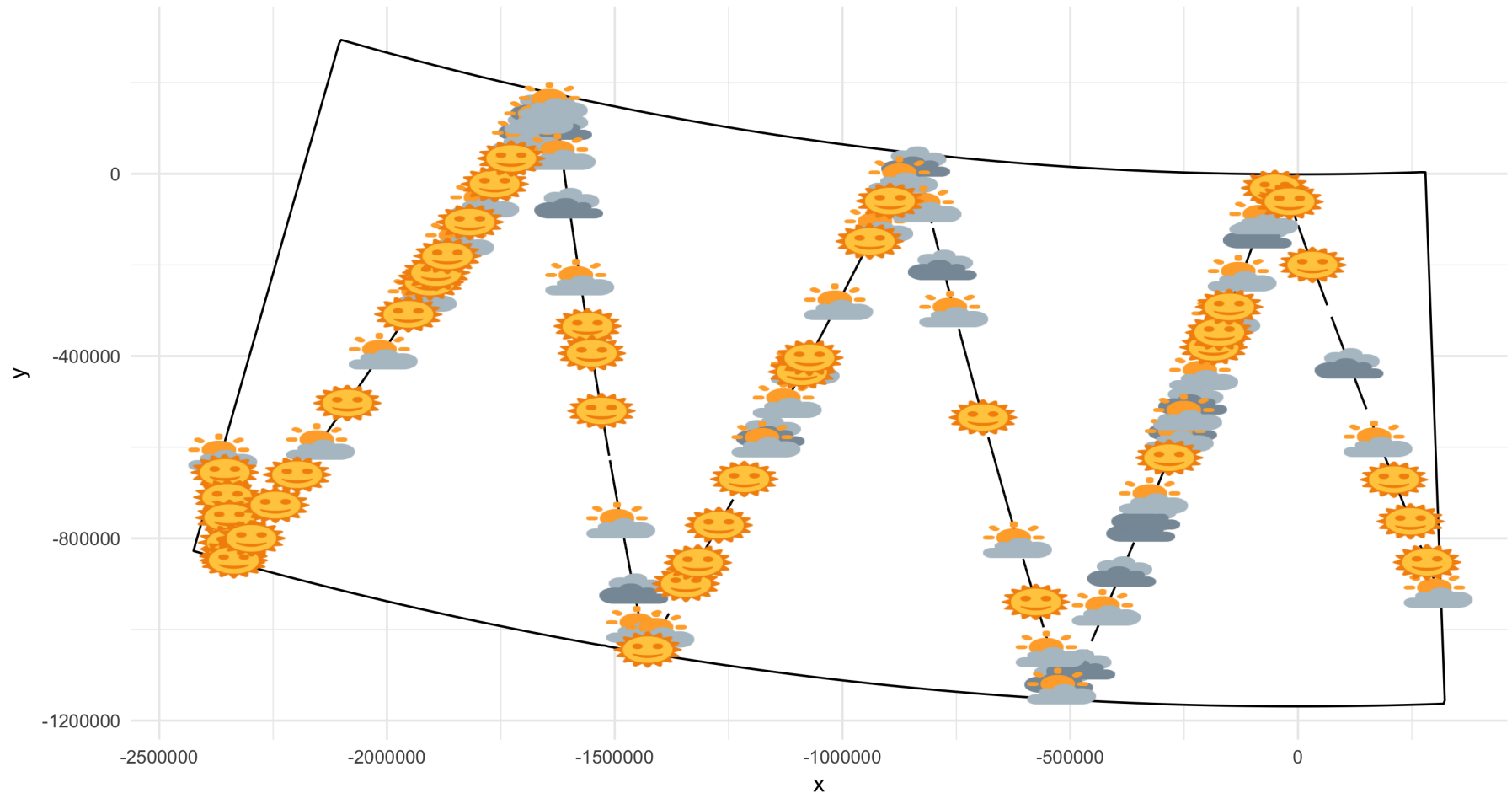
- Weather has a big effect on detectability
- Need to record during survey
- Disambiguate between distribution/detectability
- Potential confounding can be BAD



OR



# Visibility during POWER 2014

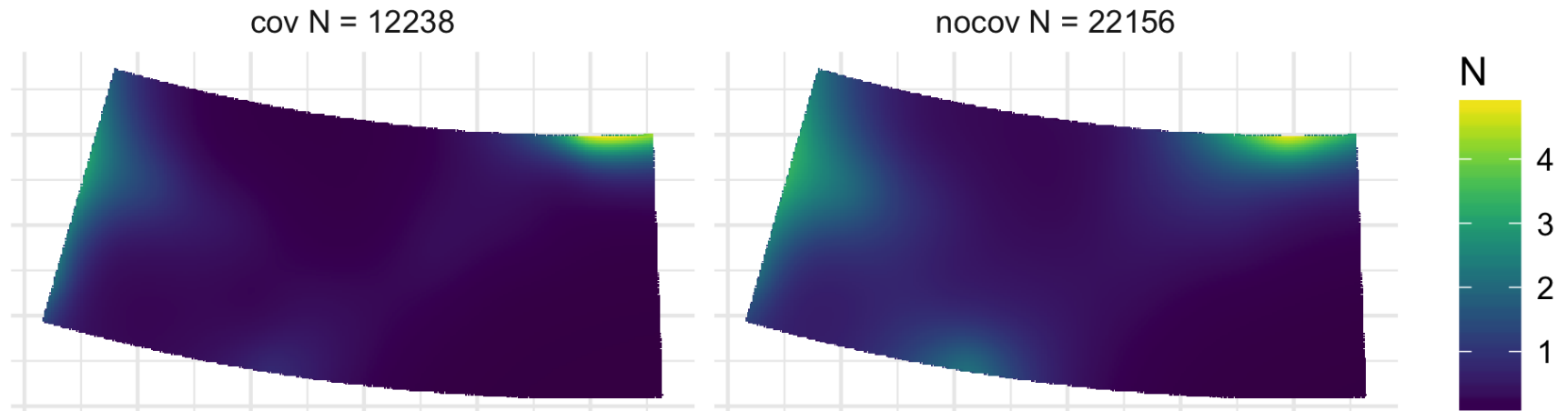


Thanks to Hiroto Murase and co. for this data!



# Covariates can make a big difference!

- Same data, same spatial model
- With weather covariates and without



# Disappointment

- Sometimes you don't have enough data
- Or, enough coverage
- Or, the right covariates

**Sometimes, you can't build a spatial model**

# Segmenting

- Example on [course site](#)
- Length of  $\approx 2w$  is reasonable
- Too big: no detail
- Too small: all 0/1
- See also [Redfern et al., \(2008\)](#)

# Getting help

# Resources

- [Course reading list](#) has pointers to these topics
- [DenMod wiki](#) with FAQ and more
- Distance sampling Google Group
  - Friendly, helpful, low traffic
  - see [distancesampling.org/distancelist.html](https://distancesampling.org/distancelist.html)

# Recent developments

- DenMod project has produced lots of methodology
- Fitting complicated models
- Fitting DSMs in JAGS/Nimble
- dsmextra

That's all folks!