Phylogenetic Multilevel Models for Tree Traits at Arnold Arboretum

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4/12/2018

Study Questions:

1. How is phenology related to other traits?
2. What predicts climate sensitivity? +Functional traits? +Phylogeny? +Amount of climate change experienced?

Field Methods:

The following trait data were collected in 2014 and 2015, from 360 individuals across 65 species of trees, all of which were of known wild origin and were growing at the Arnold Arboretum, Boston, MAssachusetts, USA: 1. Annual growth (from increment cores) 2. Climate sensitivity (from increment cores); 3. Phenology- spring budburst and leaf out dates, fall leaf color and senescence dates 4. Height 5. Leaf mass and leaf area 6. Wood density (from twigs)

Phylogenetic methods:

The complete list of taxa included in the phylogeny can be found in supplementary Table 1. In addition to the taxa included in the study, two species were added to stabilize the topology of the tree (so that the resulting phylogeny would be congruent with that of the APGIII phylogeny without having to include topological constraints in the tree search), Salix discolour and Acer saccharum, and one for placing a fossil constraint, Nelumbo nucifera. Sequences from the chloroplast genes rbcL, matK and trnL were downloaded from NCBI (Supplementary Table 2) and were aligned with MAFFT using the default settings. ##Phylogenetic analysis The phylogenetic analysis was performed with BEAST vers. 1.8.2. This software implements a Bayesian approach that infer rooted ultrametic trees (i.e., with all species equidistant from the root), which is very useful for comparative evolutionary analyses. A distinct GTR + rho + I nucleotide substitution model was used for the three markers. This model was either the best model as selected by the Aikake Information Criterion (AIC) in jModeltest when fitting the models on ML tree (phyml + NNI tree swapping), or it received significant AIC weights (greater than 0.2). We placed four fossil constraints on the tree to calibrate the (relaxed) molecular clock (Table X). We followed Beaulieu et al. for the choice of constraints and for the prior probabilities on the tree (see Beaulieu et al. for complete justification).

Phylogenetic multilevel models

Using BRMS (Stan) to fit phylogenetic multilevel models of trait relationships (eventually will use similar models to predict climate sensitivity, too).

```
## Warning: package 'dplR' was built under R version 3.4.3

##
## Attaching package: 'dplyr'

## The following objects are masked from 'package:plyr':
##
##     arrange, count, desc, failwith, id, mutate, rename, summarise,
```

```
##     summarize

## The following objects are masked from 'package:stats':
##
##     filter, lag

## The following objects are masked from 'package:base':
##
##     intersect, setdiff, setequal, union

## Warning: package 'lme4' was built under R version 3.4.3

## Loading required package: Matrix

## Loading required package: Rcpp

## Warning: package 'Rcpp' was built under R version 3.4.4

## Loading required package: ggplot2

## Loading 'brms' package (version 2.1.8). Useful instructions
## can be found by typing help('brms'). A more detailed introduction
## to the package is available through vignette('brms_overview').
## Run theme_set(theme_default()) to use the default bayesplot theme.

##
## Attaching package: 'brms'

## The following object is masked from 'package:lme4':
##
##     ngrps

## Loading required package: coda

## Joining, by = c("AccNum", "SpName")
```

We want to model phenology as a function of traits (height, wood density, lma), with and without controlling for phylogeny.

Multilevel model without phylogeny

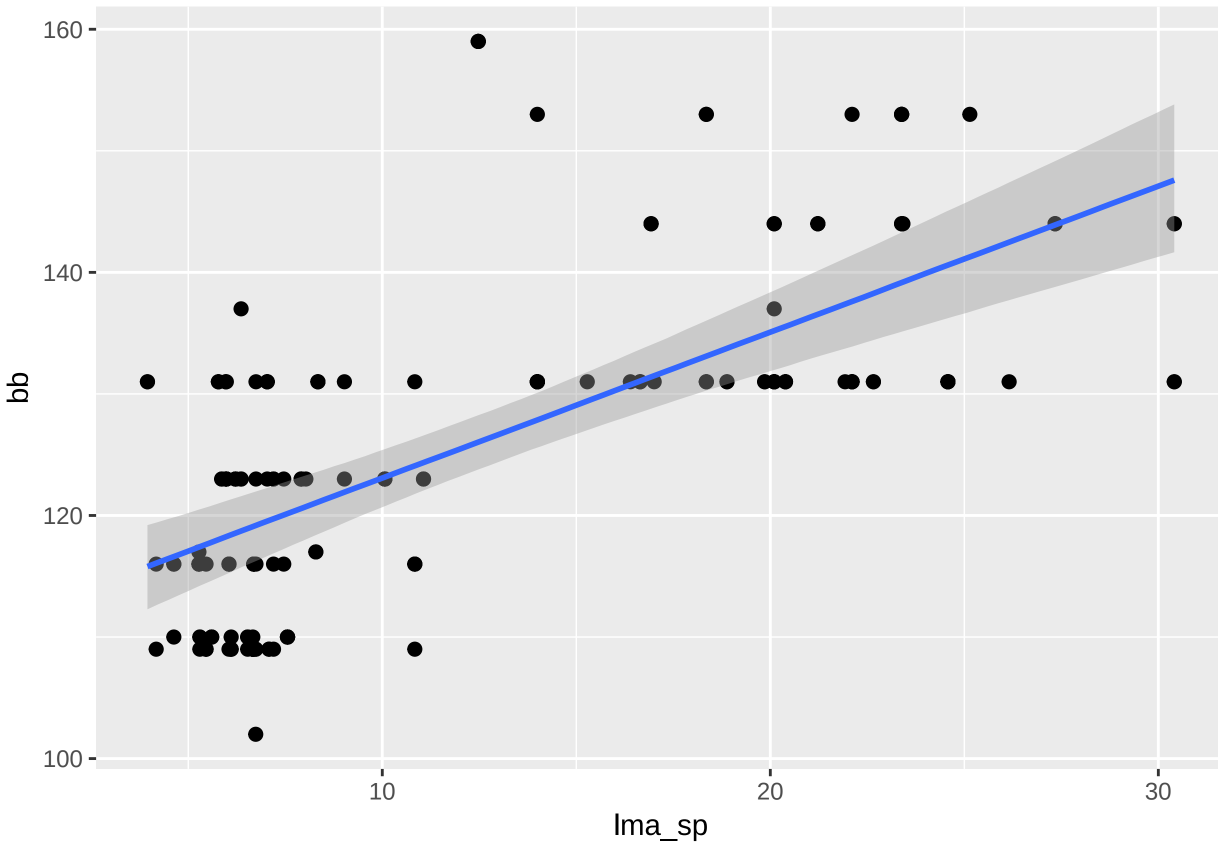
First, a model of budburst as a function of leaf mass area, without controlling for phylogeny, and including all species (gymnosperms and angiosperms):

```
bb_lma.mod<- brm(bb ~ lma_sp + (1|sp),
                     data = traits3, family = gaussian(),
                    sample_prior = TRUE, chains = 2, cores = 2,
                     iter = 4000, warmup = 1000)
```

```
## Compiling the C++ model

## Start sampling
```

```
#head(coef(bb_lma.mod))
```



Multilevel model with phylogeny

Now, a model of budburst as a function of leaf mass area, including the phylogeny:

```
bb_lma_phylo.mod<- brm(bb ~ lma_sp + (1|phylo) + (1|sp),
                     data = traits3, family = gaussian(),
                     cov_ranef = list(phylo = A),
                    sample_prior = TRUE, chains = 2, cores = 2,
                     iter = 4000, warmup = 1000,
                    control = list(adapt_delta = 0.99))
```

```
## Compiling the C++ model
## Start sampling
```

```
head(coef(bb_lma_phylo.mod))
```

```
## $phylo
## , , Intercept
##
##                                Estimate Est.Error  2.5%ile 97.5%ile
## Aesculus_flava                 111.5261  3.933052 103.6464 119.5453
## Betula_alleghaniensis          111.6759  3.315318 105.1663 118.5290
## Betula_nigra                   111.6507  3.313731 104.9873 118.5154
## Carya_glabra                   110.7296  3.298390 104.0901 117.2041
## Carya_ovata                    110.7282  3.294001 104.1115 117.0842
## Catalpa_speciosa               115.2031  4.985506 107.2339 126.4672
## Cedrus_libani                  115.0849  6.668490 104.0037 130.2159
```

```
## Chamaecyparis_thyoides       114.7048  5.577335 104.9352 126.8985
## Crataegus_crus-galli         109.7237  3.268935 102.8496 115.8098
## Fagus_engleriana             112.3329  3.281889 106.0367 119.1614
## Fagus_grandifolia            112.3425  3.318768 106.1349 119.4700
## Fraxinus_chinensis           114.1931  4.197141 106.9353 123.2010
## Fraxinus_pennsylvanica       113.9182  4.065152 106.8593 122.8163
## Gleditsia_triacanthos        114.6982  4.845018 107.1708 125.8780
## Larix_decidua                110.3409  4.265753 101.5770 118.7374
## Larix_kaempferi              110.3650  4.274474 101.6136 118.6588
## Larix_sibirica               110.3414  4.267229 101.6614 118.6514
## Liquidambar_styraciflua      113.9578  4.653739 106.1761 124.6177
## Liriodendron_tulipifera      112.2179  4.505127 103.4999 121.7887
## Metasequoia_glyptostroboides 113.8402  5.098243 104.4234 124.7040
## Phellodendron_amurense       113.0598  4.237722 105.6026 122.5600
## Picea_asperata               115.3899  6.363756 104.9316 129.4622
## Picea_engelmannii            115.2567  6.314140 104.7948 129.1532
## Picea_koraiensis             115.3956  6.358886 104.9082 129.6255
## Picea_koyamai                115.4748  6.426866 104.9131 129.8319
## Picea_meyeri                 115.3901  6.365040 104.9104 129.4130
## Picea_obovata                115.4100  6.361577 105.0393 129.6208
## Picea_pungens                115.4642  6.448180 104.9634 129.9044
## Picea_purpurea               115.3738  6.334059 104.9617 129.4016
## Picea_rubens                 115.4898  6.433492 104.9798 130.1120
## Picea_wilsonii               115.3889  6.340763 104.9788 129.2910
## Pinus_densiflora             117.7917  7.178290 106.4283 133.5173
## Pinus_echinata               118.3747  7.680330 106.4199 135.4486
## Pinus_koraiensis             116.8952  6.848546 105.9977 131.7042
## Pinus_nigra                  117.7031  7.140777 106.3135 133.5012
## Pinus_ponderosa              118.2211  7.574659 106.3266 135.0534
## Pinus_resinosa               117.7215  7.148208 106.2631 133.5191
## Pinus_sylvestris             117.7469  7.147996 106.4584 133.4947
## Pinus_tabuliformis           117.7926  7.232805 106.3945 133.8610
## Pinus_thunbergii             117.8387  7.266411 106.3699 133.9818
## Platanus_occidentalis        115.3397  5.406464 106.9216 127.5805
## Populus_deltoides            112.9591  4.307429 105.3709 122.7718
## Pseudotsuga_menziesii        112.0089  4.827445 102.4595 122.2197
## Pyrus_calleryana             109.5118  3.186824 102.7572 115.4470
## Pyrus_pyrifolia              109.5108  3.174828 102.9022 115.4014
## Pyrus_ussuriensis            109.5111  3.168765 102.8646 115.4010
## Quercus_aliena               114.4087  3.915863 107.6530 122.7395
## Quercus_coccinea             114.3205  3.871040 107.5734 122.6110
## Quercus_dentata              114.5001  3.974316 107.6934 122.9253
## Quercus_glandulifera         114.4229  3.914934 107.6679 122.7127
## Quercus_rubra                114.1511  3.844015 107.4512 122.7086
## Quercus_variabilis           114.3670  3.907540 107.6542 122.8229
## Sorbus_yuana                 109.5068  3.210194 102.7165 115.5027
## Styphnolobium_japonicum      114.5296  4.675599 107.1009 125.4744
## Taxus_cuspidata              114.1100  6.270211 102.9436 128.4124
## Thuja_plicata                115.4518  6.099224 105.4573 128.9672
## Tilia_americana              112.7446  4.214908 105.1192 121.9432
## Zelkova_serrata              111.6540  3.692659 104.5948 119.6234
##
## , , lma_sp
##
```

```
##                               Estimate Est.Error   2.5%ile 97.5%ile
## Aesculus_flava               0.9718345 0.3053796 0.3198851 1.495238
## Betula_alleghaniensis        0.9718345 0.3053796 0.3198851 1.495238
## Betula_nigra                 0.9718345 0.3053796 0.3198851 1.495238
## Carya_glabra                 0.9718345 0.3053796 0.3198851 1.495238
## Carya_ovata                  0.9718345 0.3053796 0.3198851 1.495238
## Catalpa_speciosa             0.9718345 0.3053796 0.3198851 1.495238
## Cedrus_libani                0.9718345 0.3053796 0.3198851 1.495238
## Chamaecyparis_thyoides       0.9718345 0.3053796 0.3198851 1.495238
## Crataegus_crus-galli         0.9718345 0.3053796 0.3198851 1.495238
## Fagus_engleriana             0.9718345 0.3053796 0.3198851 1.495238
## Fagus_grandifolia            0.9718345 0.3053796 0.3198851 1.495238
## Fraxinus_chinensis           0.9718345 0.3053796 0.3198851 1.495238
## Fraxinus_pennsylvanica       0.9718345 0.3053796 0.3198851 1.495238
## Gleditsia_triacanthos        0.9718345 0.3053796 0.3198851 1.495238
## Larix_decidua                0.9718345 0.3053796 0.3198851 1.495238
## Larix_kaempferi              0.9718345 0.3053796 0.3198851 1.495238
## Larix_sibirica               0.9718345 0.3053796 0.3198851 1.495238
## Liquidambar_styraciflua      0.9718345 0.3053796 0.3198851 1.495238
## Liriodendron_tulipifera      0.9718345 0.3053796 0.3198851 1.495238
## Metasequoia_glyptostroboides 0.9718345 0.3053796 0.3198851 1.495238
## Phellodendron_amurense       0.9718345 0.3053796 0.3198851 1.495238
## Picea_asperata               0.9718345 0.3053796 0.3198851 1.495238
## Picea_engelmannii            0.9718345 0.3053796 0.3198851 1.495238
## Picea_koraiensis             0.9718345 0.3053796 0.3198851 1.495238
## Picea_koyamai                0.9718345 0.3053796 0.3198851 1.495238
## Picea_meyeri                 0.9718345 0.3053796 0.3198851 1.495238
## Picea_obovata                0.9718345 0.3053796 0.3198851 1.495238
## Picea_pungens                0.9718345 0.3053796 0.3198851 1.495238
## Picea_purpurea               0.9718345 0.3053796 0.3198851 1.495238
## Picea_rubens                 0.9718345 0.3053796 0.3198851 1.495238
## Picea_wilsonii               0.9718345 0.3053796 0.3198851 1.495238
## Pinus_densiflora             0.9718345 0.3053796 0.3198851 1.495238
## Pinus_echinata               0.9718345 0.3053796 0.3198851 1.495238
## Pinus_koraiensis             0.9718345 0.3053796 0.3198851 1.495238
## Pinus_nigra                  0.9718345 0.3053796 0.3198851 1.495238
## Pinus_ponderosa              0.9718345 0.3053796 0.3198851 1.495238
## Pinus_resinosa               0.9718345 0.3053796 0.3198851 1.495238
## Pinus_sylvestris             0.9718345 0.3053796 0.3198851 1.495238
## Pinus_tabuliformis           0.9718345 0.3053796 0.3198851 1.495238
## Pinus_thunbergii             0.9718345 0.3053796 0.3198851 1.495238
## Platanus_occidentalis        0.9718345 0.3053796 0.3198851 1.495238
## Populus_deltoides            0.9718345 0.3053796 0.3198851 1.495238
## Pseudotsuga_menziesii        0.9718345 0.3053796 0.3198851 1.495238
## Pyrus_calleryana             0.9718345 0.3053796 0.3198851 1.495238
## Pyrus_pyrifolia              0.9718345 0.3053796 0.3198851 1.495238
## Pyrus_ussuriensis            0.9718345 0.3053796 0.3198851 1.495238
## Quercus_aliena               0.9718345 0.3053796 0.3198851 1.495238
## Quercus_coccinea             0.9718345 0.3053796 0.3198851 1.495238
## Quercus_dentata              0.9718345 0.3053796 0.3198851 1.495238
## Quercus_glandulifera         0.9718345 0.3053796 0.3198851 1.495238
## Quercus_rubra                0.9718345 0.3053796 0.3198851 1.495238
## Quercus_variabilis           0.9718345 0.3053796 0.3198851 1.495238
## Sorbus_yuana                 0.9718345 0.3053796 0.3198851 1.495238
```

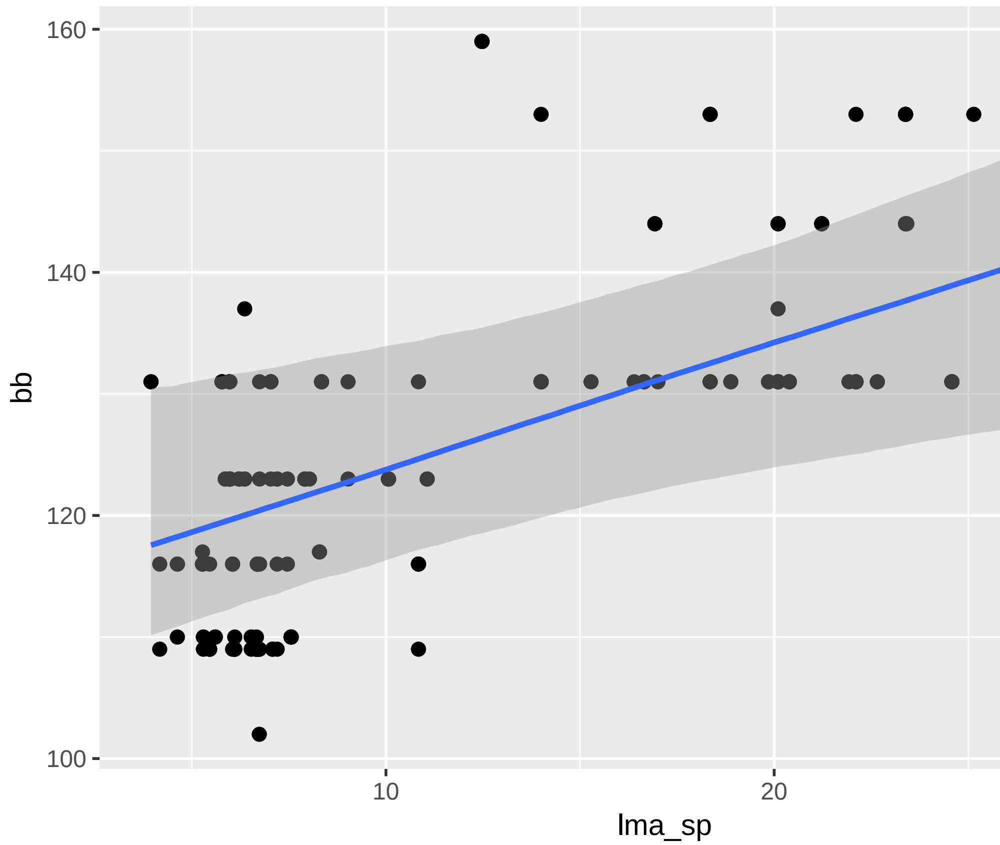
```
## Styphnolobium_japonicum      0.9718345 0.3053796 0.3198851 1.495238
## Taxus_cuspidata              0.9718345 0.3053796 0.3198851 1.495238
## Thuja_plicata                0.9718345 0.3053796 0.3198851 1.495238
## Tilia_americana              0.9718345 0.3053796 0.3198851 1.495238
## Zelkova_serrata              0.9718345 0.3053796 0.3198851 1.495238
##
##
## $sp
## , , Intercept
##
##                              Estimate Est.Error   2.5%ile 97.5%ile
## Aesculus_flava               107.3071  6.915811  96.16965 123.7892
## Betula_alleghaniensis        113.6467  6.740857 102.86754 129.6823
## Betula_nigra                 111.5023  6.618797 100.99172 127.2155
## Carya_glabra                 106.8389  7.332493  95.71625 124.8362
## Carya_ovata                  108.9853  7.070652  97.86603 125.8991
## Catalpa_speciosa             124.5683  6.033675 112.26882 137.1660
## Cedrus_libani                115.3505  6.975691 103.63632 131.6303
## Chamaecyparis_thyoides       112.4448  6.513079 100.67985 127.2452
## Crataegus_crus-galli         111.9507  8.036950  99.58865 130.6007
## Fagus_engleriana             111.9764  6.306791 101.35430 126.8604
## Fagus_grandifolia            111.5578  7.103124  99.52645 127.6977
## Fraxinus_chinensis           120.2330  5.984361 109.35362 134.3164
## Fraxinus_pennsylvanica       106.6659  7.090859  93.78232 122.0629
## Gleditsia_triacanthos        121.7790  6.230153 110.04008 135.5610
## Larix_decidua                105.4217  7.052959  94.73696 122.2811
## Larix_kaempferi              108.7663  7.450446  96.25089 125.7804
## Larix_sibirica               107.5843  7.145686  96.31091 124.6112
## Liquidambar_styraciflua      116.9821  6.330317 105.36914 131.1089
## Liriodendron_tulipifera      111.3254  6.777103  99.97206 127.0101
## Metasequoia_glyptostroboides 112.0243  6.042388 101.33364 126.4990
## Phellodendron_amurense       118.0823  6.177814 107.29348 131.9952
## Picea_asperata               106.6921  7.209220  94.42546 122.9464
## Picea_engelmannii            107.4214  8.105882  93.10886 125.0104
## Picea_koraiensis             114.2721  6.596759 102.09077 128.4359
## Picea_koyamai                124.8361  6.812212 112.95324 140.2435
## Picea_meyeri                 110.6583  6.404701  99.52521 125.2273
## Picea_obovata                113.8177  6.666314 101.73241 128.1368
## Picea_pungens                116.2487  7.784194 102.69426 133.5705
## Picea_purpurea               110.3898  7.416813  97.17199 126.6162
## Picea_rubens                 121.6941  6.480757 110.59675 136.2041
## Picea_wilsonii               118.3818  5.190295 109.31022 130.3110
## Pinus_densiflora             123.1634  5.728140 112.29207 135.3776
## Pinus_echinata               140.4892  5.299536 129.20253 150.8577
## Pinus_koraiensis             113.9845  6.635831 101.98645 128.4560
## Pinus_nigra                  107.1854  6.919040  94.41064 122.6222
## Pinus_ponderosa              105.1390  7.949615  91.14308 122.4131
## Pinus_resinosa               117.4376  6.901086 105.09536 132.3459
## Pinus_sylvestris             109.4785  6.410218  97.75470 123.2921
## Pinus_tabuliformis           110.1445  6.397822  98.42092 124.3590
## Pinus_thunbergii             122.2031  7.380226 108.60419 137.5914
## Platanus_occidentalis        121.1890  6.079655 108.95696 134.5684
## Populus_deltoides            114.7279  6.844344 103.37874 130.8603
## Pseudotsuga_menziesii        116.9050  7.813748 104.29407 134.6773
```

```
## Pyrus_calleryana              108.9839  7.309867  97.49232 125.7879
## Pyrus_pyrifolia               110.0120  7.114268  98.62358 126.2349
## Pyrus_ussuriensis             110.7507  7.084741  99.73126 127.7745
## Quercus_aliena                116.9605  5.939779 106.02883 130.4864
## Quercus_coccinea              115.4014  6.025904 104.80513 128.9791
## Quercus_dentata               124.1586  5.756336 113.16318 137.0658
## Quercus_glandulifera          118.3173  5.581457 108.18198 131.1562
## Quercus_rubra                 115.2686  6.848977 102.33290 129.9192
## Quercus_variabilis            117.7690  6.511540 105.83175 132.4495
## Sorbus_yuana                  107.8712  7.232440  96.98650 124.5848
## Styphnolobium_japonicum       120.6579  6.046323 108.94820 133.8091
## Taxus_cuspidata               113.2338  7.634421 100.09387 130.1174
## Thuja_plicata                 120.5208  7.020814 108.26786 136.0986
## Tilia_americana               114.0863  6.837257 102.51142 129.5686
## Zelkova_serrata               112.4332  6.656065 101.65657 127.8701
##
## , , lma_sp
##
##                                Estimate Est.Error   2.5%ile 97.5%ile
## Aesculus_flava                0.9718345 0.3053796 0.3198851 1.495238
## Betula_alleghaniensis         0.9718345 0.3053796 0.3198851 1.495238
## Betula_nigra                  0.9718345 0.3053796 0.3198851 1.495238
## Carya_glabra                  0.9718345 0.3053796 0.3198851 1.495238
## Carya_ovata                   0.9718345 0.3053796 0.3198851 1.495238
## Catalpa_speciosa              0.9718345 0.3053796 0.3198851 1.495238
## Cedrus_libani                 0.9718345 0.3053796 0.3198851 1.495238
## Chamaecyparis_thyoides        0.9718345 0.3053796 0.3198851 1.495238
## Crataegus_crus-galli          0.9718345 0.3053796 0.3198851 1.495238
## Fagus_engleriana              0.9718345 0.3053796 0.3198851 1.495238
## Fagus_grandifolia             0.9718345 0.3053796 0.3198851 1.495238
## Fraxinus_chinensis            0.9718345 0.3053796 0.3198851 1.495238
## Fraxinus_pennsylvanica        0.9718345 0.3053796 0.3198851 1.495238
## Gleditsia_triacanthos         0.9718345 0.3053796 0.3198851 1.495238
## Larix_decidua                 0.9718345 0.3053796 0.3198851 1.495238
## Larix_kaempferi               0.9718345 0.3053796 0.3198851 1.495238
## Larix_sibirica                0.9718345 0.3053796 0.3198851 1.495238
## Liquidambar_styraciflua       0.9718345 0.3053796 0.3198851 1.495238
## Liriodendron_tulipifera       0.9718345 0.3053796 0.3198851 1.495238
## Metasequoia_glyptostroboides 0.9718345 0.3053796 0.3198851 1.495238
## Phellodendron_amurense        0.9718345 0.3053796 0.3198851 1.495238
## Picea_asperata                0.9718345 0.3053796 0.3198851 1.495238
## Picea_engelmannii             0.9718345 0.3053796 0.3198851 1.495238
## Picea_koraiensis              0.9718345 0.3053796 0.3198851 1.495238
## Picea_koyamai                 0.9718345 0.3053796 0.3198851 1.495238
## Picea_meyeri                  0.9718345 0.3053796 0.3198851 1.495238
## Picea_obovata                 0.9718345 0.3053796 0.3198851 1.495238
## Picea_pungens                 0.9718345 0.3053796 0.3198851 1.495238
## Picea_purpurea                0.9718345 0.3053796 0.3198851 1.495238
## Picea_rubens                  0.9718345 0.3053796 0.3198851 1.495238
## Picea_wilsonii                0.9718345 0.3053796 0.3198851 1.495238
## Pinus_densiflora              0.9718345 0.3053796 0.3198851 1.495238
## Pinus_echinata                0.9718345 0.3053796 0.3198851 1.495238
## Pinus_koraiensis              0.9718345 0.3053796 0.3198851 1.495238
## Pinus_nigra                   0.9718345 0.3053796 0.3198851 1.495238
```

```
## Pinus_ponderosa              0.9718345 0.3053796 0.3198851 1.495238
## Pinus_resinosa               0.9718345 0.3053796 0.3198851 1.495238
## Pinus_sylvestris             0.9718345 0.3053796 0.3198851 1.495238
## Pinus_tabuliformis           0.9718345 0.3053796 0.3198851 1.495238
## Pinus_thunbergii             0.9718345 0.3053796 0.3198851 1.495238
## Platanus_occidentalis        0.9718345 0.3053796 0.3198851 1.495238
## Populus_deltoides            0.9718345 0.3053796 0.3198851 1.495238
## Pseudotsuga_menziesii        0.9718345 0.3053796 0.3198851 1.495238
## Pyrus_calleryana             0.9718345 0.3053796 0.3198851 1.495238
## Pyrus_pyrifolia              0.9718345 0.3053796 0.3198851 1.495238
## Pyrus_ussuriensis            0.9718345 0.3053796 0.3198851 1.495238
## Quercus_aliena               0.9718345 0.3053796 0.3198851 1.495238
## Quercus_coccinea             0.9718345 0.3053796 0.3198851 1.495238
## Quercus_dentata              0.9718345 0.3053796 0.3198851 1.495238
## Quercus_glandulifera         0.9718345 0.3053796 0.3198851 1.495238
## Quercus_rubra                0.9718345 0.3053796 0.3198851 1.495238
## Quercus_variabilis           0.9718345 0.3053796 0.3198851 1.495238
## Sorbus_yuana                 0.9718345 0.3053796 0.3198851 1.495238
## Styphnolobium_japonicum      0.9718345 0.3053796 0.3198851 1.495238
## Taxus_cuspidata              0.9718345 0.3053796 0.3198851 1.495238
## Thuja_plicata                0.9718345 0.3053796 0.3198851 1.495238
## Tilia_americana              0.9718345 0.3053796 0.3198851 1.495238
## Zelkova_serrata              0.9718345 0.3053796 0.3198851 1.495238
```

```r
#test for phylogenetic signal
hyp <- "sd_phylo__Intercept^2 / (sd_phylo__Intercept^2 + sigma^2) = 0"
(hyp <- hypothesis(bb_lma_phylo.mod, hyp, class = NULL))
```

```
## Hypothesis Tests for class :
##                Hypothesis Estimate Est.Error CI.Lower CI.Upper Evid.Ratio
## 1 (sd_phylo__Interc... = 0     0.55      0.29        0     0.91        0.6
##   Star
## 1    *
## ---
## '*': The expected value under the hypothesis lies outside the 95%-CI.
```



Lambda=0.55 so a phylogenetic signal?

Multilevel model with phylogeny and with individual variation in predictor trait

Now we will update the model with individual variability in leaf mass area:

```
traits3$lma_spvar <- traits3$lma - traits3$lma_sp
bb_lma_phylo_ind.mod <- update(bb_lma_phylo.mod, formula = ~ . + lma_spvar,
                        newdata = traits3, chains = 2, cores = 2,
                        iter = 4000, warmup = 1000)
```

```
## Start sampling
```

```
summary(bb_lma_phylo_ind.mod)#
```

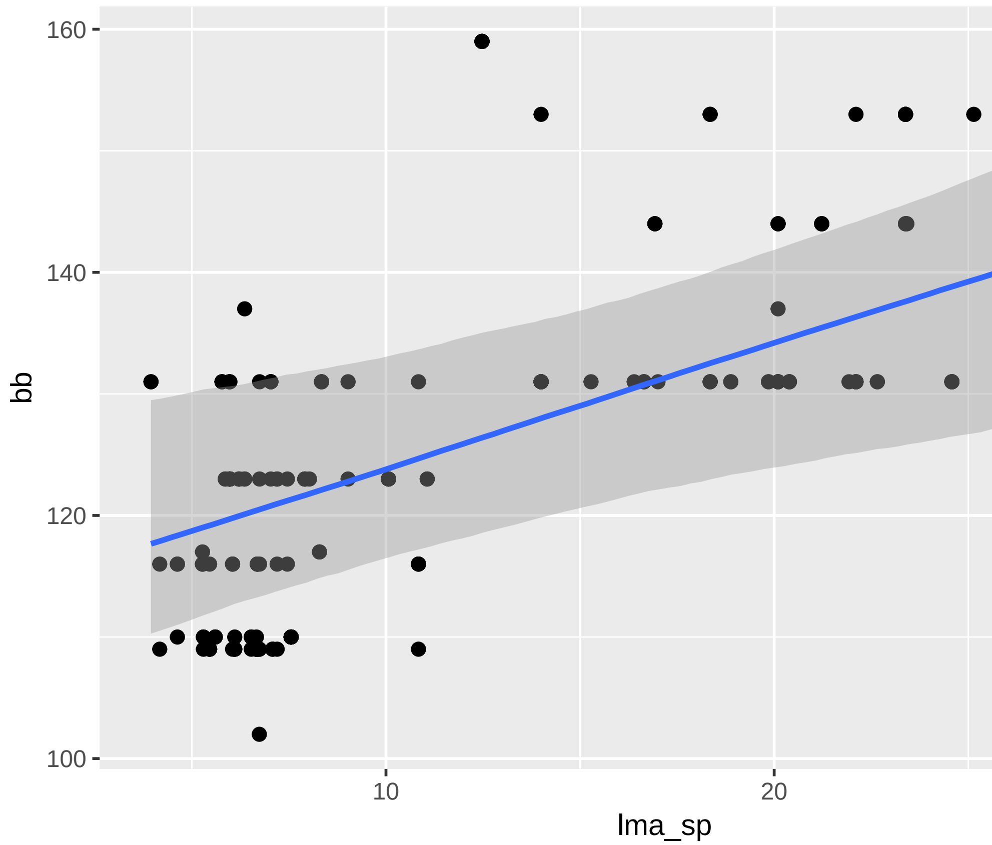
```
##  Family: gaussian
##   Links: mu = identity; sigma = identity
## Formula: bb ~ lma_sp + (1 | phylo) + (1 | sp) + lma_spvar
##    Data: traits3 (Number of observations: 206)
## Samples: 2 chains, each with iter = 4000; warmup = 1000; thin = 1;
##          total post-warmup samples = 6000
##     ICs: LOO = NA; WAIC = NA; R2 = NA
##
## Group-Level Effects:
## ~phylo (Number of levels: 58)
##               Estimate Est.Error l-95% CI u-95% CI Eff.Sample Rhat
## sd(Intercept)     6.29      3.93     0.29    14.63        422 1.00
##
## ~sp (Number of levels: 58)
```

```
##               Estimate Est.Error l-95% CI u-95% CI Eff.Sample Rhat
## sd(Intercept)     7.52      1.07     5.54     9.68       1014 1.00
##
## Population-Level Effects:
##           Estimate Est.Error l-95% CI u-95% CI Eff.Sample Rhat
## Intercept   114.63      5.55   105.60   127.30       1084 1.00
## lma_sp        0.96      0.31     0.30     1.48        703 1.00
## lma_spvar    -0.11      0.14    -0.39     0.17       6000 1.00
##
## Family Specific Parameters:
##       Estimate Est.Error l-95% CI u-95% CI Eff.Sample Rhat
## sigma     4.62      0.27     4.12     5.20       6000 1.00
##
## Samples were drawn using sampling(NUTS). For each parameter, Eff.Sample
## is a crude measure of effective sample size, and Rhat is the potential
## scale reduction factor on split chains (at convergence, Rhat = 1).
```

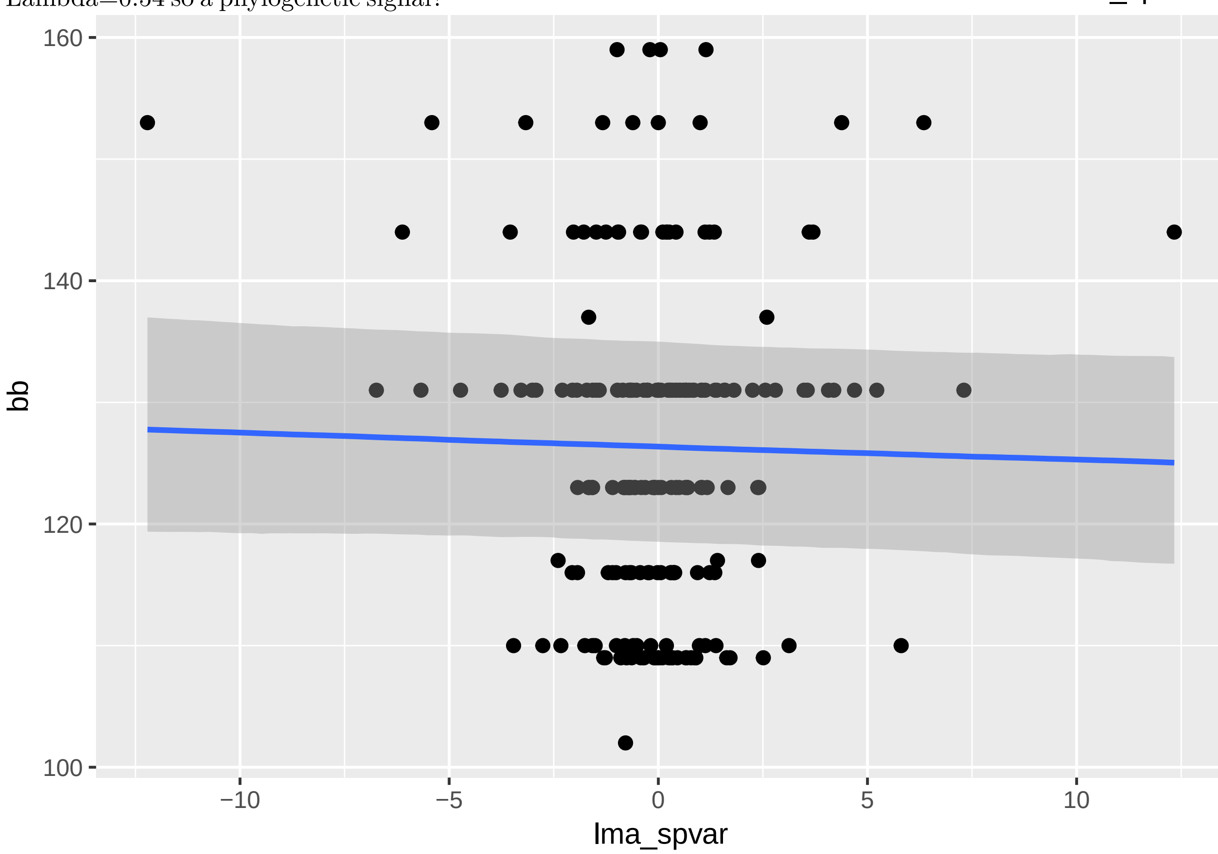
```
#plot(marginal_effects(bb_lma_phylo_ind.mod), points = TRUE)

#test for phylogenetic signal
hyp <- "sd_phylo__Intercept^2 / (sd_phylo__Intercept^2 + sigma^2) = 0"
(hyp <- hypothesis(bb_lma_phylo_ind.mod, hyp, class = NULL))
```

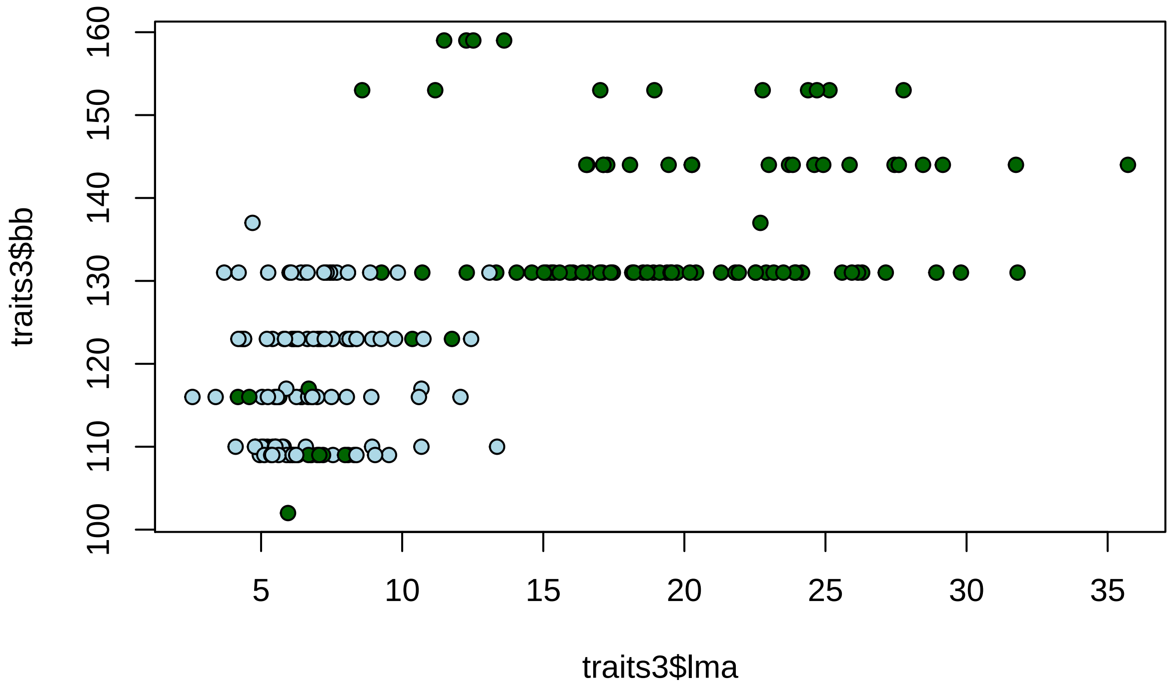
```
## Hypothesis Tests for class :
##                Hypothesis Estimate Est.Error CI.Lower CI.Upper Evid.Ratio
## 1 (sd_phylo__Interc... = 0     0.54      0.29        0     0.91       0.59
##   Star
## 1    *
## ---
## '*': The expected value under the hypothesis lies outside the 95%-CI.
```



Lambda=0.54 so a phylogenetic signal?



##Next steps: Try fitting models separately for angiosperms and gymnosperms



Questions

1. Should I analyze gymnosperms separately from angiosperms?
2. Does this approach seem reasonable?
3. Do people stil use lambda? Are there other things I should look at/report to look at phylogenetic signal?
4. Other ideas of things to do?