University of Leicester

DEPARTMENT OF GEOGRAPHY

Large scale green-up models determined from NDVI

Jörg Kaduk

Department of Geography
University of Leicester

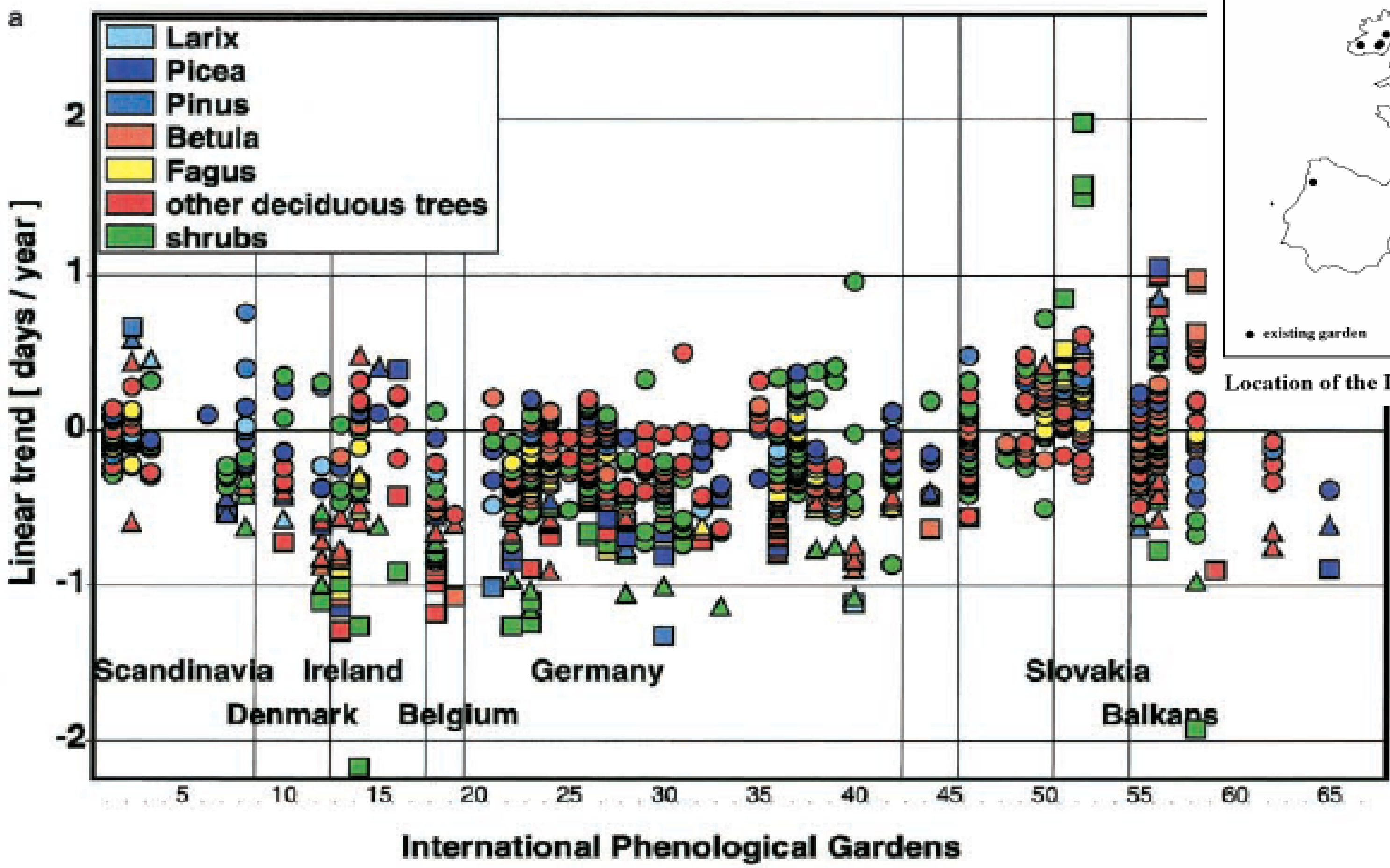
Sietse Los

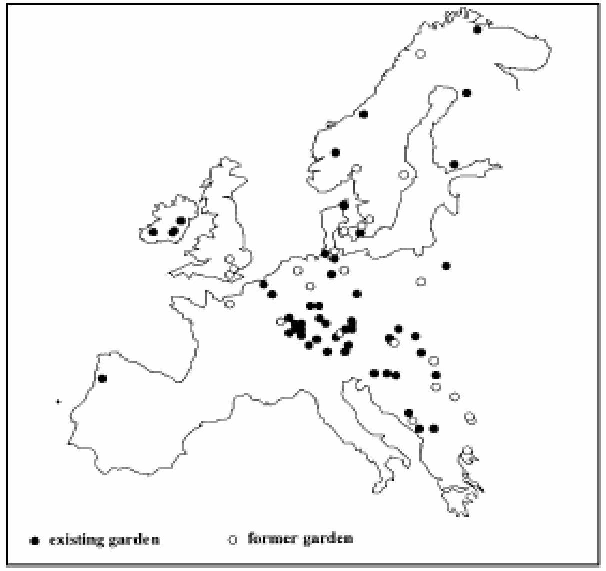
Department of Geography
University of Wales, Swansea

JULES Science meeting 2007

CLASSIC
Climate and Land Surface Systems Interaction Centre

Changes in the time of leaf out





Location of the International Phenological Gardens

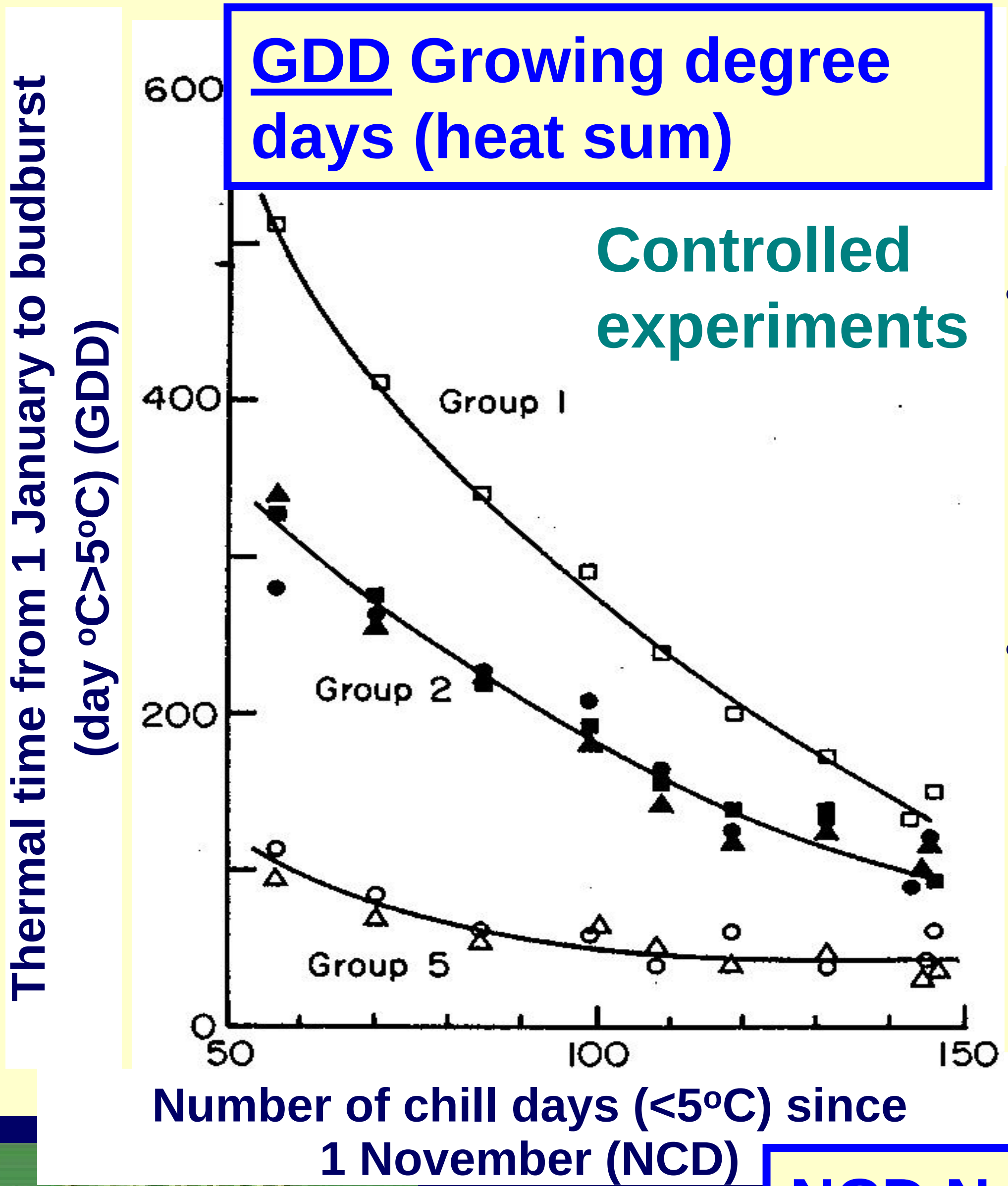
Menzel, 2000

Biome level models

- Temperate and boreal biomes
- Subtropical and tropical biomes & grasslands

Temperate & boreal biomes

GDD Growing degree days (heat sum)



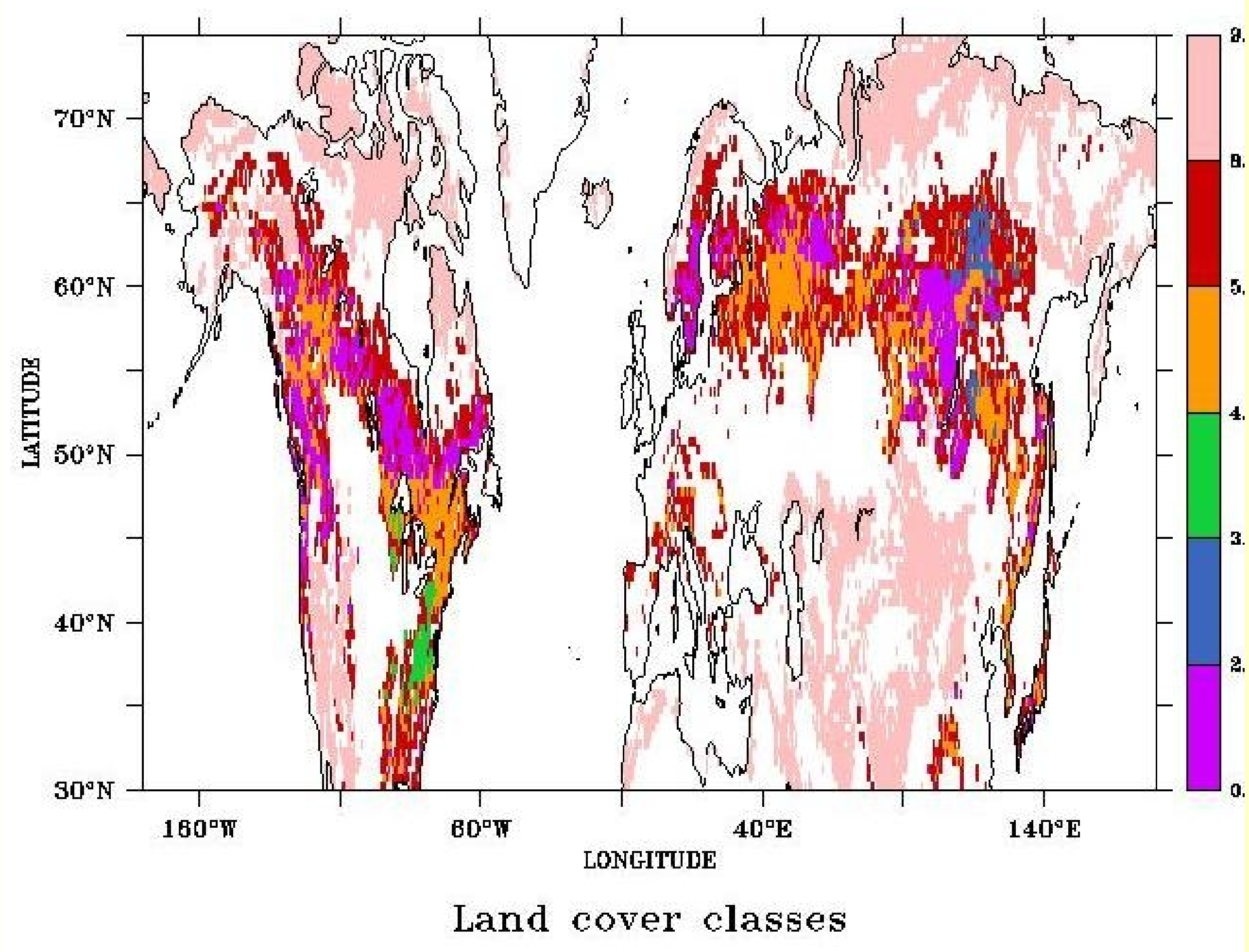
Single species observations

- **Temperate and boreal trees require a period of chilling for rapid leaf budburst in spring**
- **For single species, the heat sum required for budburst drops with increasing chilling exponentially to a threshold**

From Murray et al. (1989)

NCD Number of chilling days

Biomes evaluated



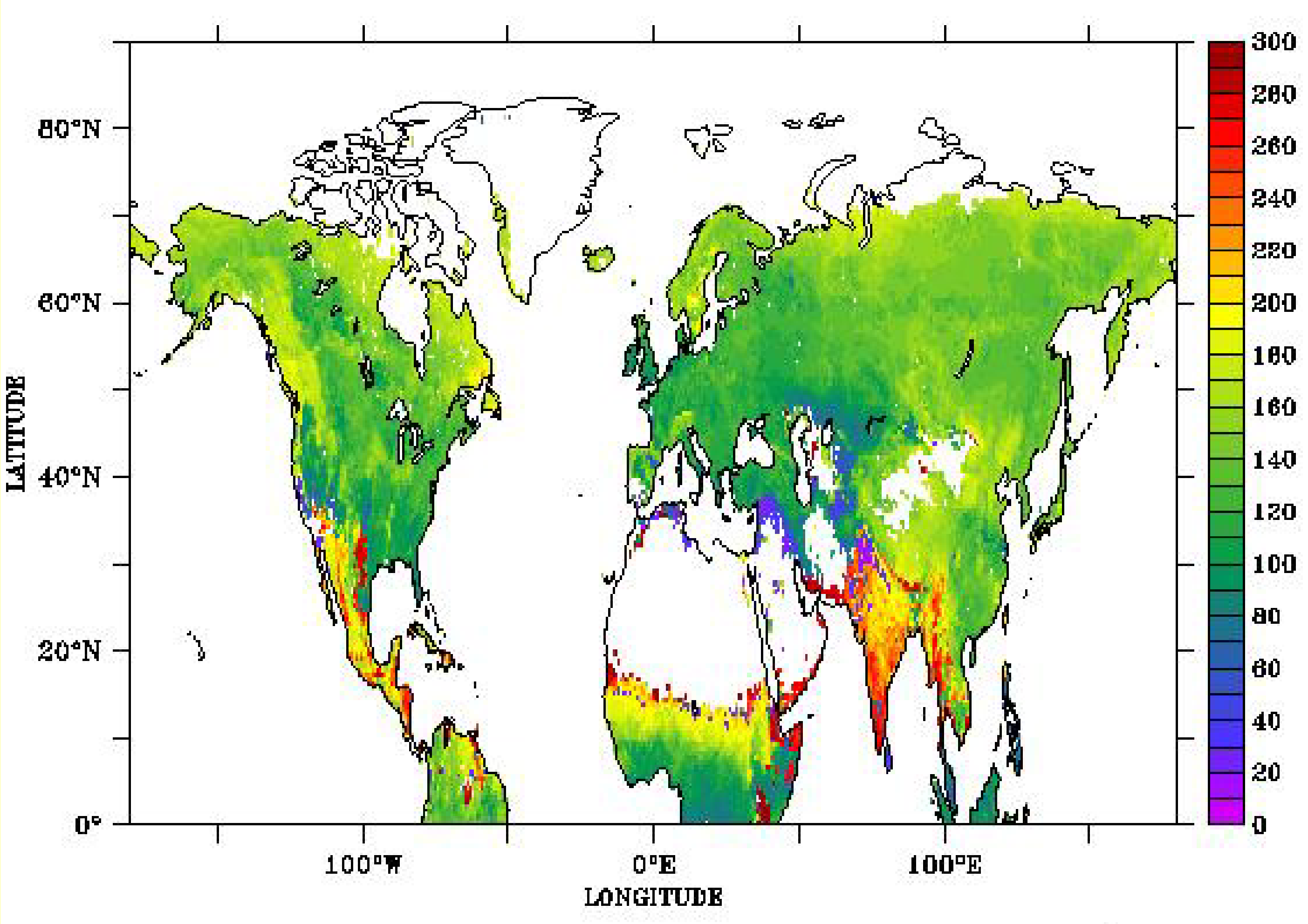
Classification of the University of Maryland land cover map into SiB2 biomes (from ISLSCP II)

- **1 Evergreen Needleleaf Forest**
- **3 Deciduous Needleleaf Forest**
- **4 Deciduous Broadleaf Forest**
- **5 Mixed Forests**
- **6 Woodlands Broadleaf Deciduous Trees**
- **9 Open Shrublands**

Procedure

- **Estimation of leaf-out date from NDVI**
- **Calculation of GDD and NCD**
- **Determination of models for leaf-out date using GDD and NCD**
  - **Models are such that leaf out occurs when GDD > F*(NCD)**
  - **Minimize error between observed and predicted GDD at leaf-out date using least squares**

Day of leaf out



Day of leaf out according to the method of White et al. (1997)

GDD-NCD relationships

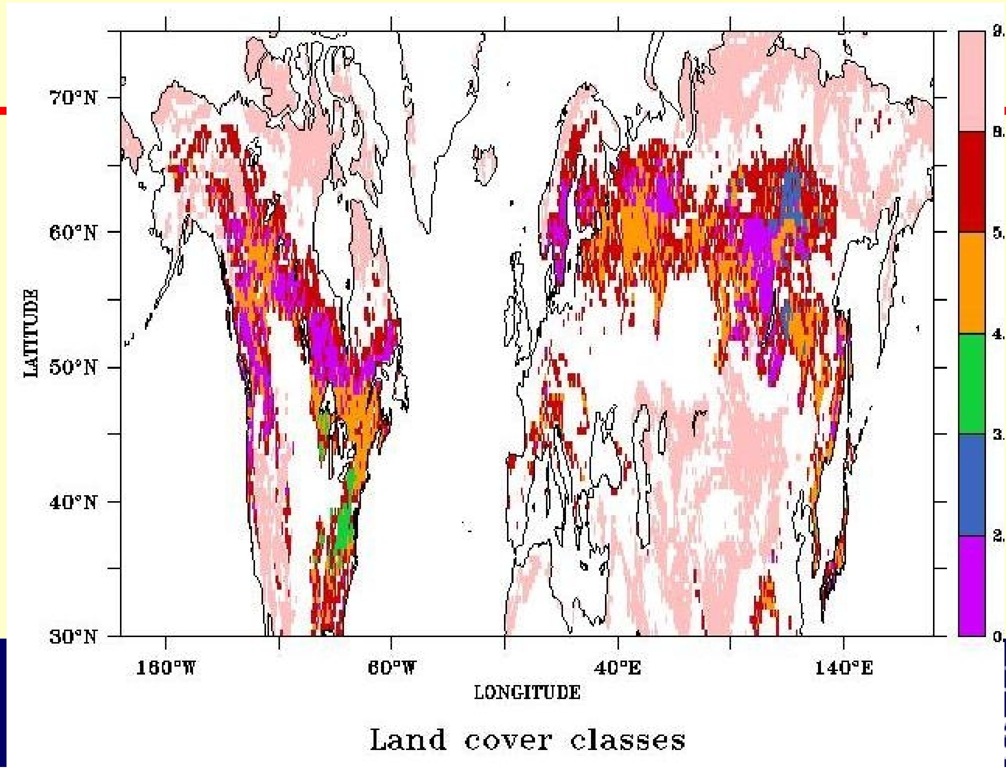
Test different functional forms relating GDD, NCD and T

a) $F^* = a$ **Biome 3**

b) $F^* = a + b \cdot \exp(-c \cdot NCD)$ **Biomes 1 & 4**

c) $F^* = (a_1 + a_2 \cdot T) + (b_1 + b_2 \cdot T) \cdot \exp(-(c_1 + c_2 \cdot T) \cdot NCD)$ **Biomes 5, 6, 9**

T mean annual temperature of previous year



CLASSIC
University of Leicester

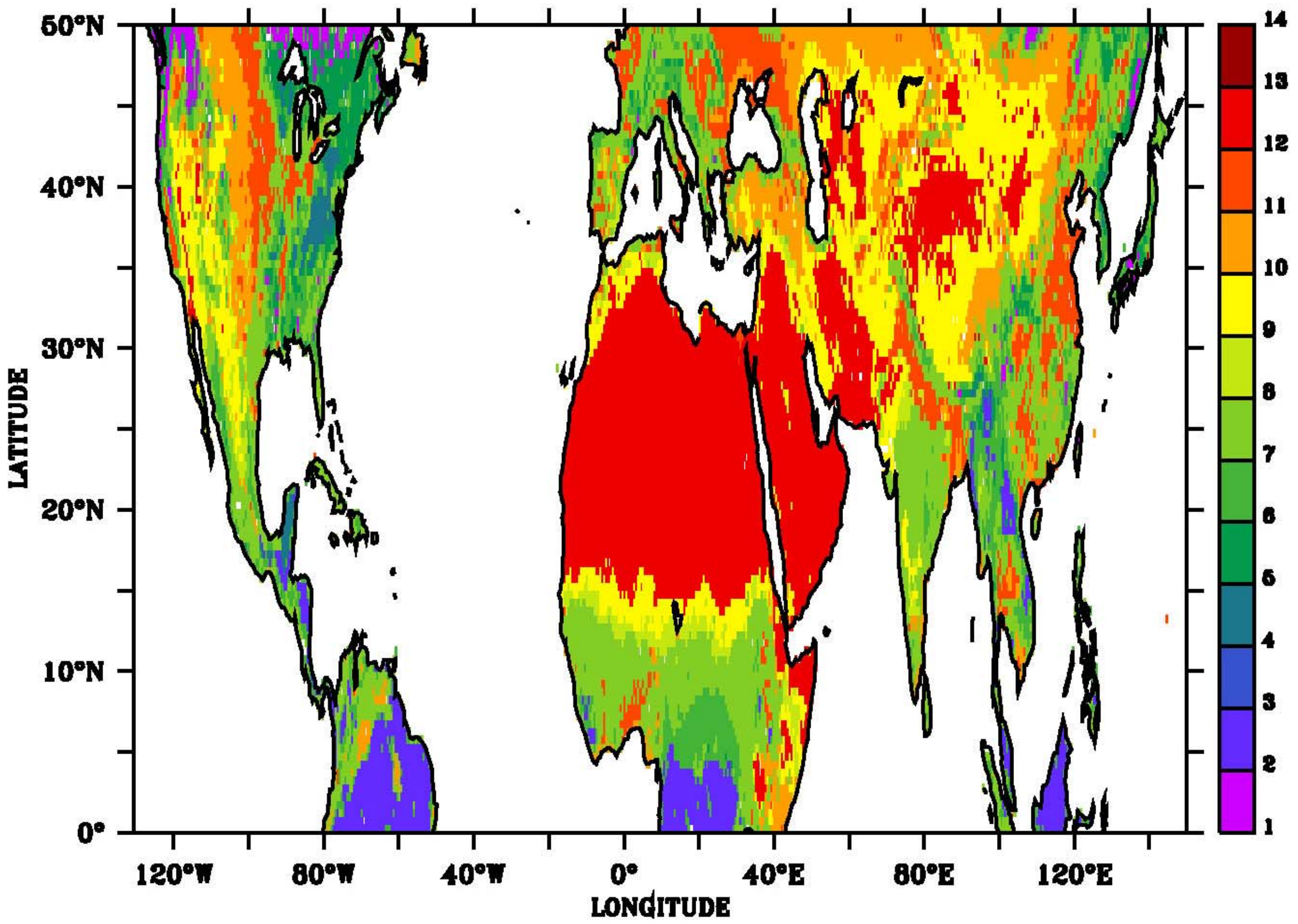
Models determined

Biome	Model for F*, $T_x=T_a$	Biome mean budburst prediction error (days)		
		Mean	Std. dev.	Range
1	$F_1(t) = 1770 - 912 \cdot \exp(-0.0033 \cdot S_c(t))$	10.18	2.79	8.7 – 13.8
3	$F_0(t) = 107$	4.82	0.42	3.6 – 5.8
4	$F_1(t) = (-951 + 2190 \cdot \exp(-0.0041 \cdot S_c(t))$	8.98	4.20	7.1 – 13.8
5	$F_3(t) = (-1820 + 7.01 \cdot T_x) + (22400 - 76.58 \cdot T_x) \cdot \exp(-(0.052 - 0.000128 \cdot T_x) \cdot S_c(t))$	7.68	1.15	6.1 – 9.7
6	$F_3(t) = (-3760 + 14.16 \cdot T_x) + (4500 - 14.44 \cdot T_x) \cdot \exp(-(0.108 - 0.000347 \cdot T_x) \cdot S_c(t))$	8.36	0.75	7.2 – 10
9	$F_3(t) = (-480 + 3.92 \cdot T_x) + (-2400 + 8.38 \cdot T_x) \cdot \exp(-(0.0456 - 0.000189 \cdot T_x) \cdot S_c(t))$	7.11	0.28	6.6 – 8.0

Tropical biomes and grasslands

Biomes

2 Evergreen Broadleaf forest
4 Broadleaf deciduous forest
5 Woodlands
7 Wooded Grasslands/ Shrublands
8 Closed Bushlands/ Shrublands
9 Open Shrublands
10 Grasslands

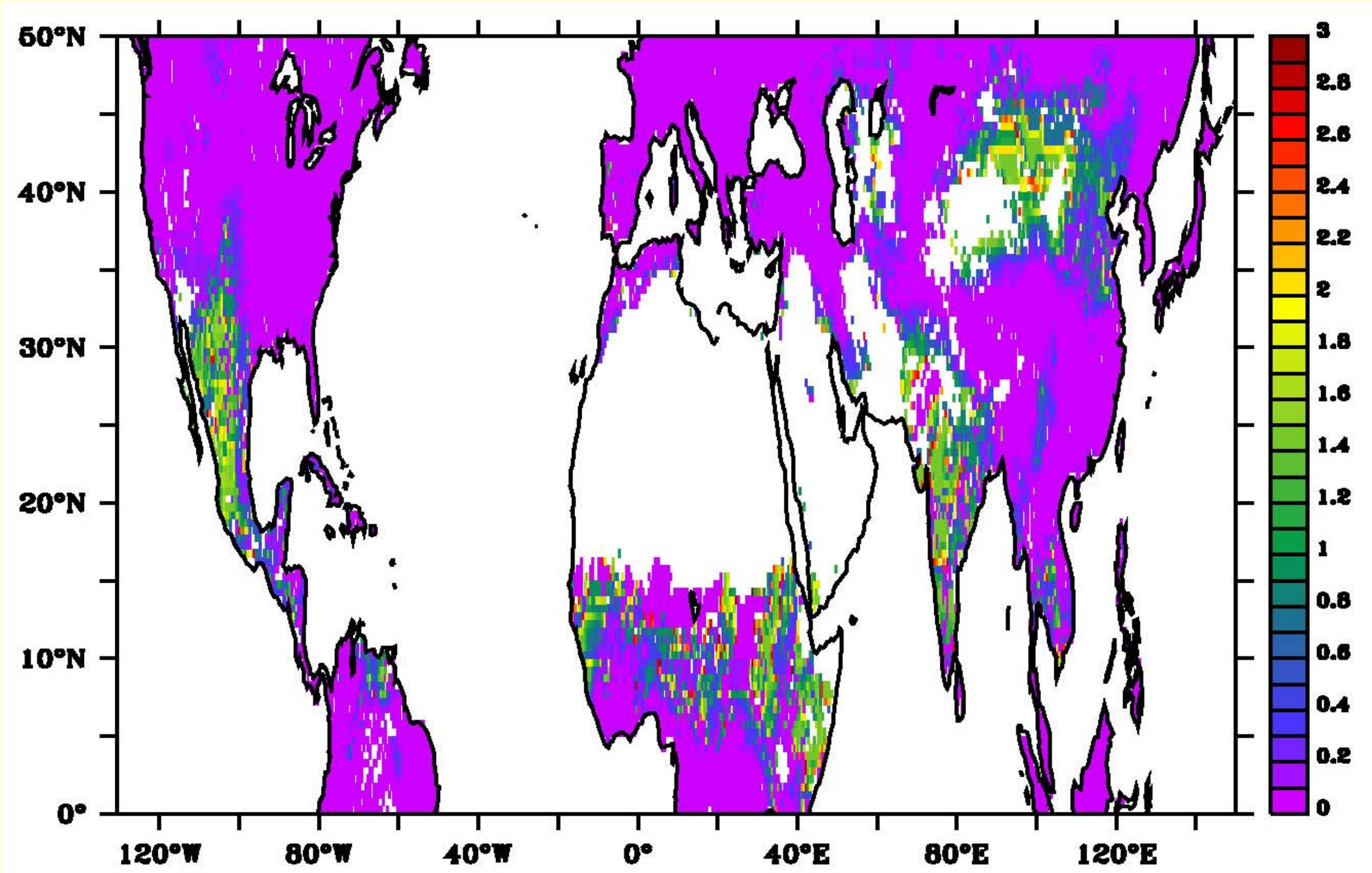


Biome (Type)

Procedure

- **Estimation of leaf-out date from NDVI**
- **Soil moisture parameters from JULES model run with GSWP2 data (Nicola Gedney, Chris Taylor)**
- **Determine relationships**
  - **Soil water potential**
  - **JULES drought stress parameter**

Soil water tension at leaf out



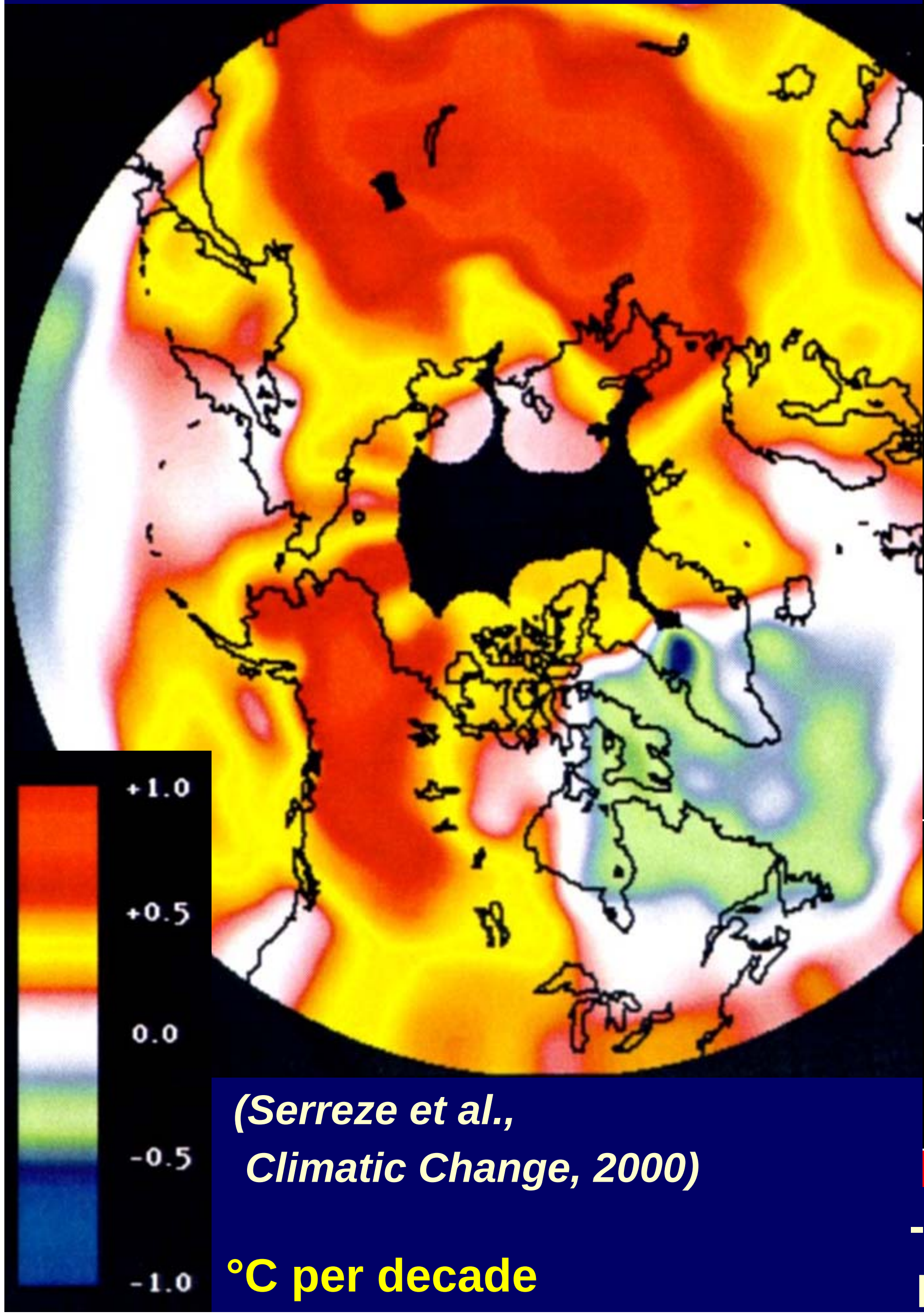
Drier areas show larger soil water potential at leaf out

Reflects adaptation of plant type to soil water availability

Conclusions

- Leaf out advanced ~ 7 days during the 80s & 90s
- Adaptations of phenology detectable using NDVI
- Crucial to use multiple years of observations to calibrate models
- We can determine meaningful large scale phenology models for temperate and boreal biomes
- Tropical biomes and grasslands require some further evaluation (different parameters, soil data)

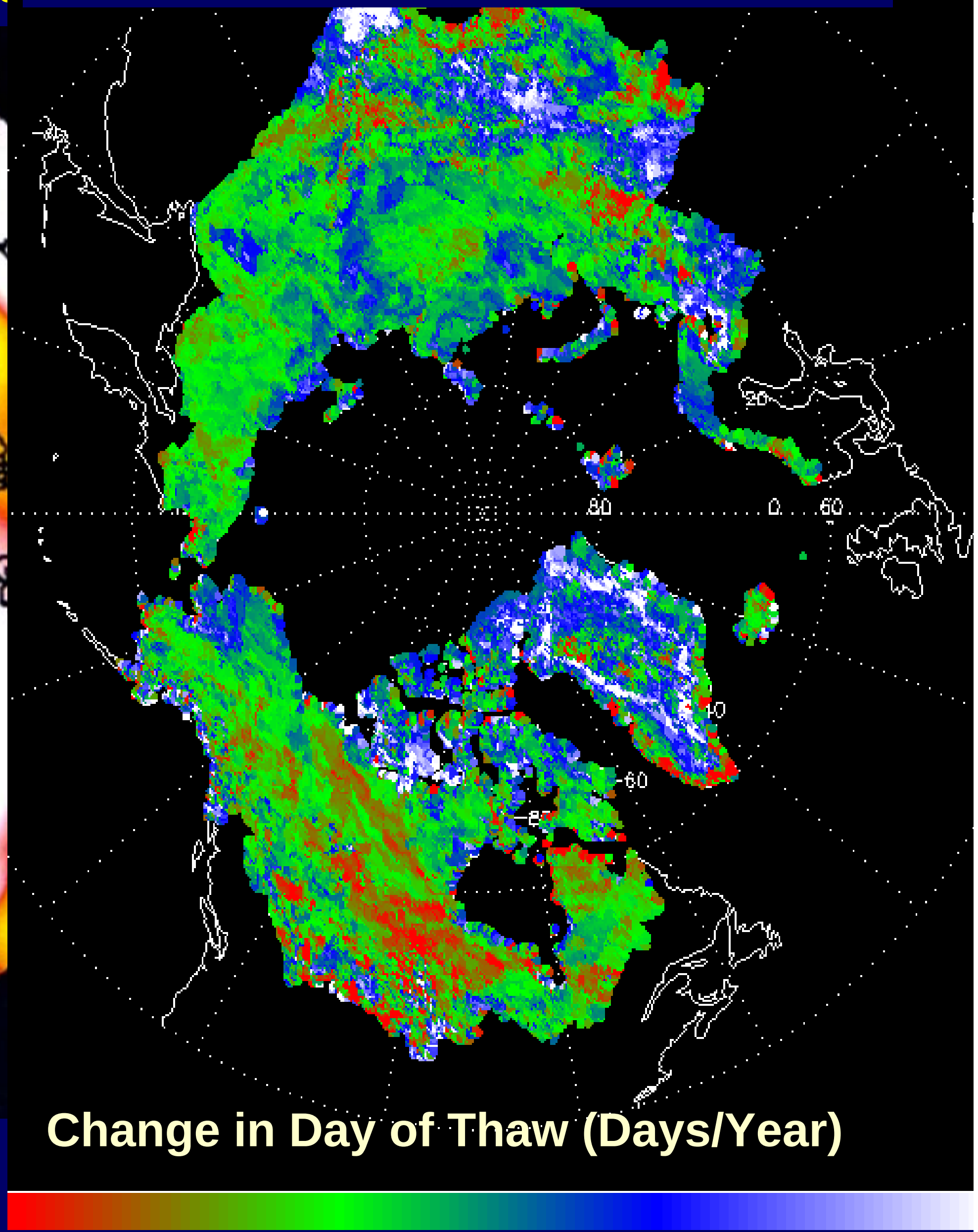
Annual High Latitude Tempera



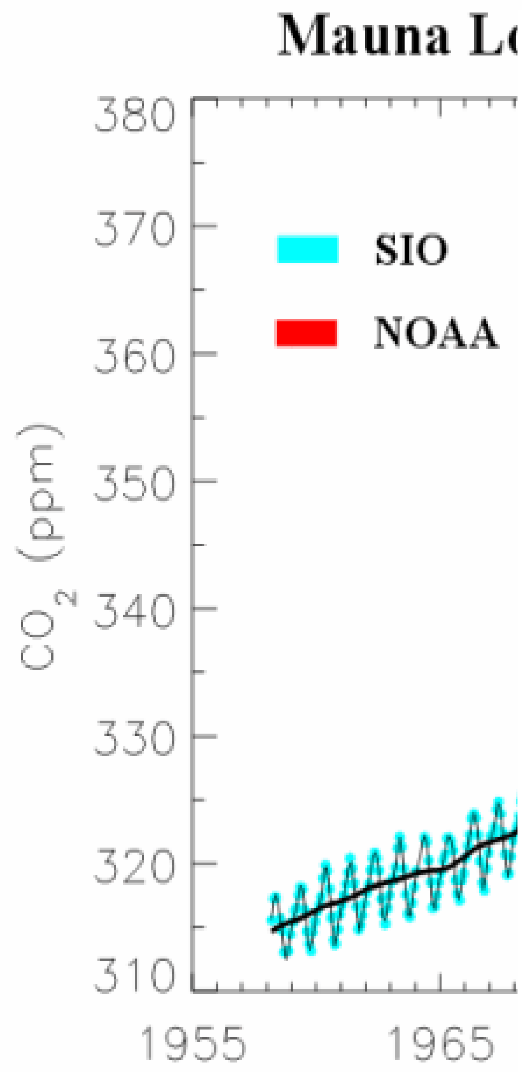
(Serreze et al., Climatic Change, 2000)

°C per decade

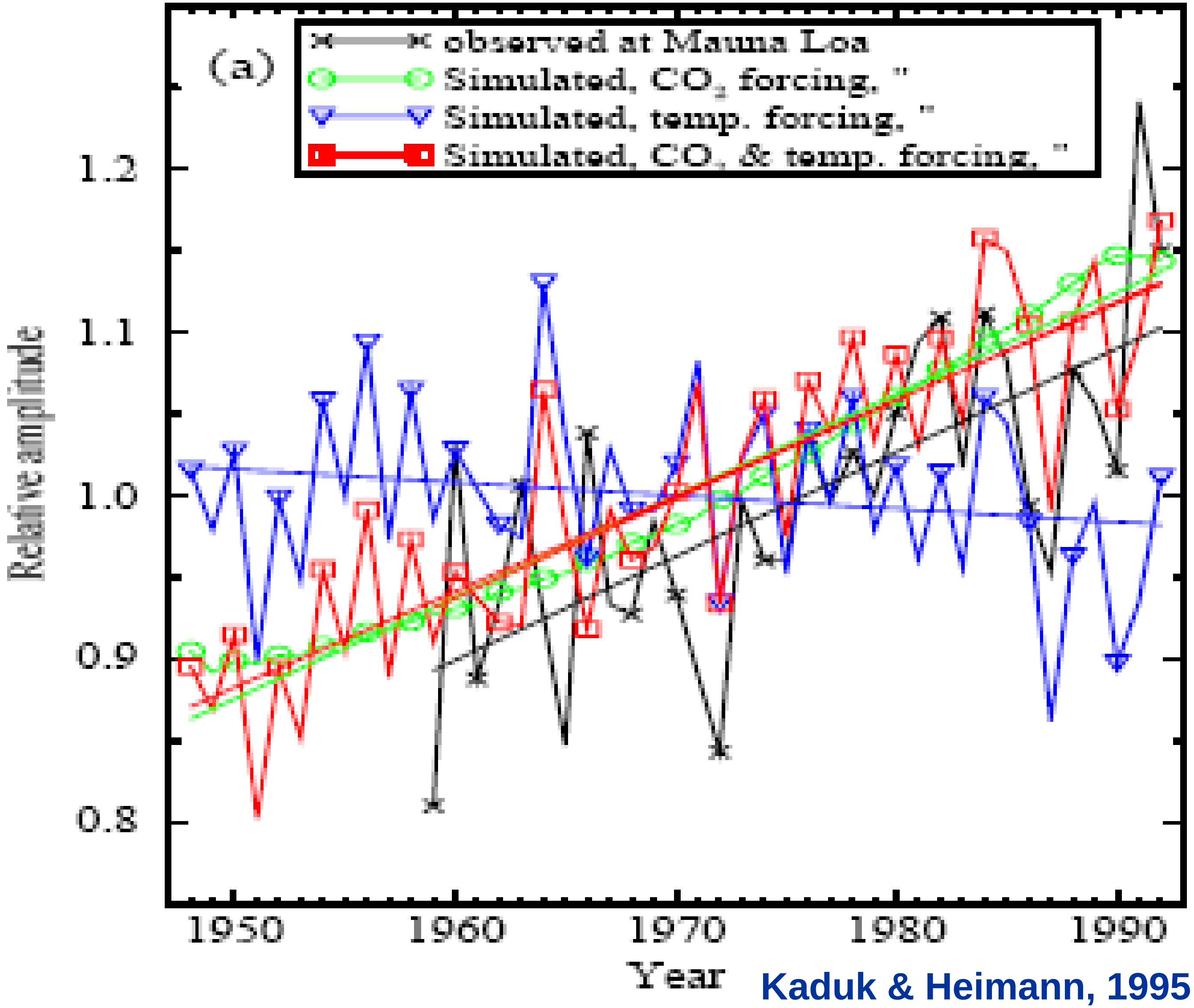
Pan-Arctic Growing Season Change



Changes in the seasonal cycle of CO_2



Amplitude of the seasonal cycle of CO_2 at Mauna Loa



Kaduk & Heimann, 1995

Motivation

Understanding and predicting the response of the terrestrial biosphere to climate variability and change requires prognostic, climate-driven canopy phenology models

Questions

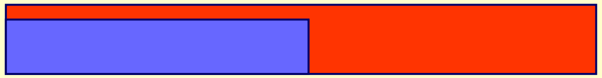
1. Do the relationships between chilling and heat accumulation carry over from single species to whole biomes, i.e. can such exponential relationships be used for modelling budburst for large scale land surface models?
2. Can consistent models be determined from large scale data?

Leaf budburst models

- Spring warming model

  - leaf budburst occurs when a fixed amount of warming has accumulated $F_0(t) = a$
- Sequential model

  - leaf budburst occurs when a fixed amount of warming was accumulated **after** a fixed amount of chilling took place
- Parallel model



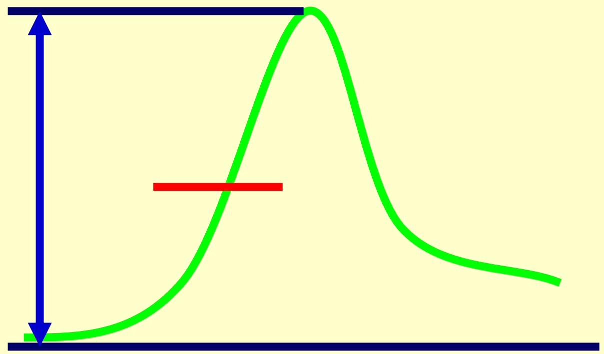
  - leaf budburst requires a fixed amount of chilling but warming accumulates in parallel to the chilling
- Alternating model
  - chilling reduces the amount of warming required, accumulate in parallel

$$F_1(t) = a + b \cdot \exp(-c \cdot \mathrm{S_c}(\mathrm{t}))$$

Estimation of leaf-out date from NDVI

NDVI data: Los et al. (2000), updated (10 daily, 0.5°), 1986-1995

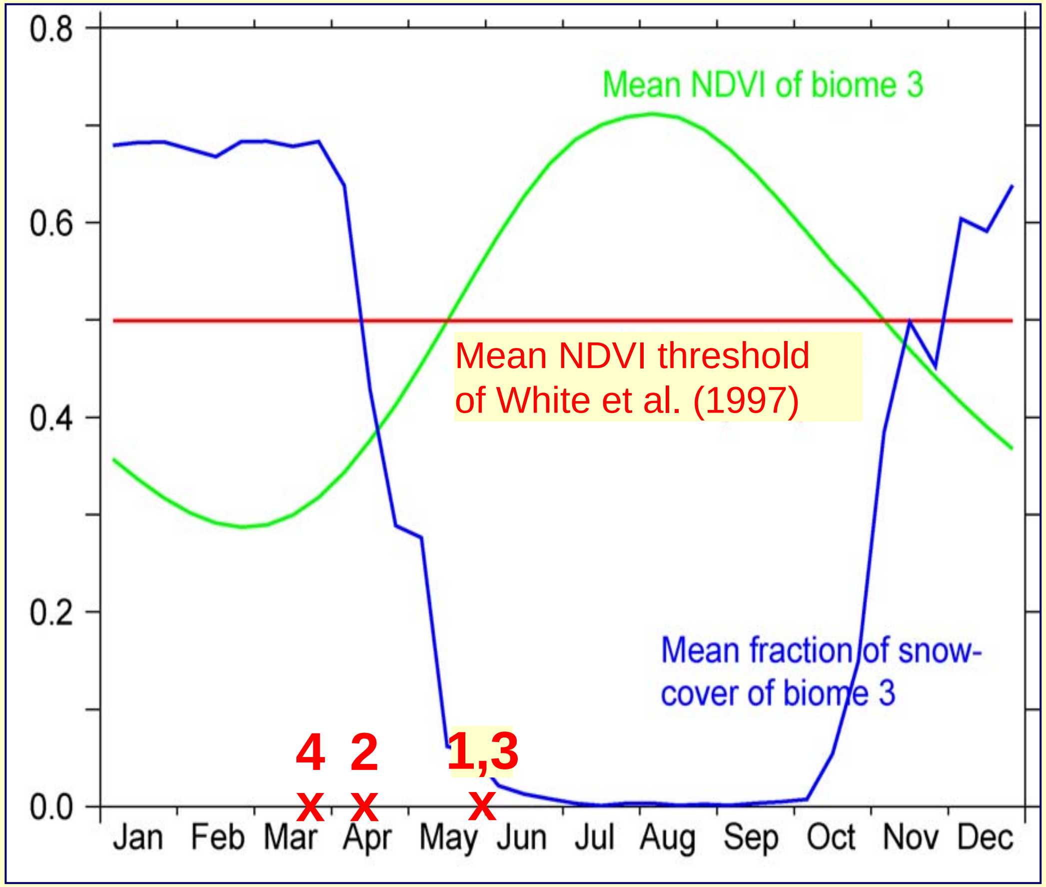
Four different methods tested for northern hemisphere:



1. **White et al. (1997)**
2. **Largest curvature (maximal 2nd derivative of a spline fit)**
3. **Kaduk & Heimann (1996), largest NDVI change after 30 day running mean temperature reached 5°C (Temperature data from GSWP2, daily, 1°)**
4. **Moulin et al. (1997), using the largest increase in the change of the NDVI above a reflectance threshold.**

Leaf-out date

- **Leaf-out dates of curvature based methods quite early**
- **Dates from methods 1 & 3 quite similar**
- **Snow data (Armstrong & Brodzik, 2002) suggest that curvature based methods detect snow melt instead of leaf-out**



- **Reject methods 2 & 4, though there might be the possibility to adjust the threshold of Moulin et al. (1997)**

Overfitting models

Prediction error

Year used to calibrate model

	1985	1986	1987	1988	1989	1990	1991	1992	1993	Ave.	Min.
1985	8.9	12.8	15.7	13.7	11.3	14.4	17.0	11.2	14.9	13.3	8.9
1986	20.0	8.9	14.2	11.0	9.3	13.0	14.3	10.3	16.6	13.1	8.9
1987	33.2	25.0	11.1	11.0	14.4	17.3	15.0	15.2	14.9	17.5	11.1
1988	33.3	25.4	15.2	10.2	14.1	15.2	17.4	14.4	16.0	17.9	10.2
1989	29.6	20.4	14.2	12.0	8.3	13.9	13.6	10.6	15.3	15.3	8.3
1990	29.6	22.2	15.7	12.0	12.5	9.5	14.8	11.5	16.5	16.0	9.5
1991	31.8	24.0	14.5	12.1	12.3	13.2	10.4	12.1	16.4	16.3	10.4
1992	28.2	21.4	13.9	11.3	10.6	12.6	13.8	9.0	15.2	15.1	9.0
1993	32.3	24.5	15.0	11.6	13.7	15.1	17.5	13.9	14.0	17.5	14.0

Leave one out cross validation

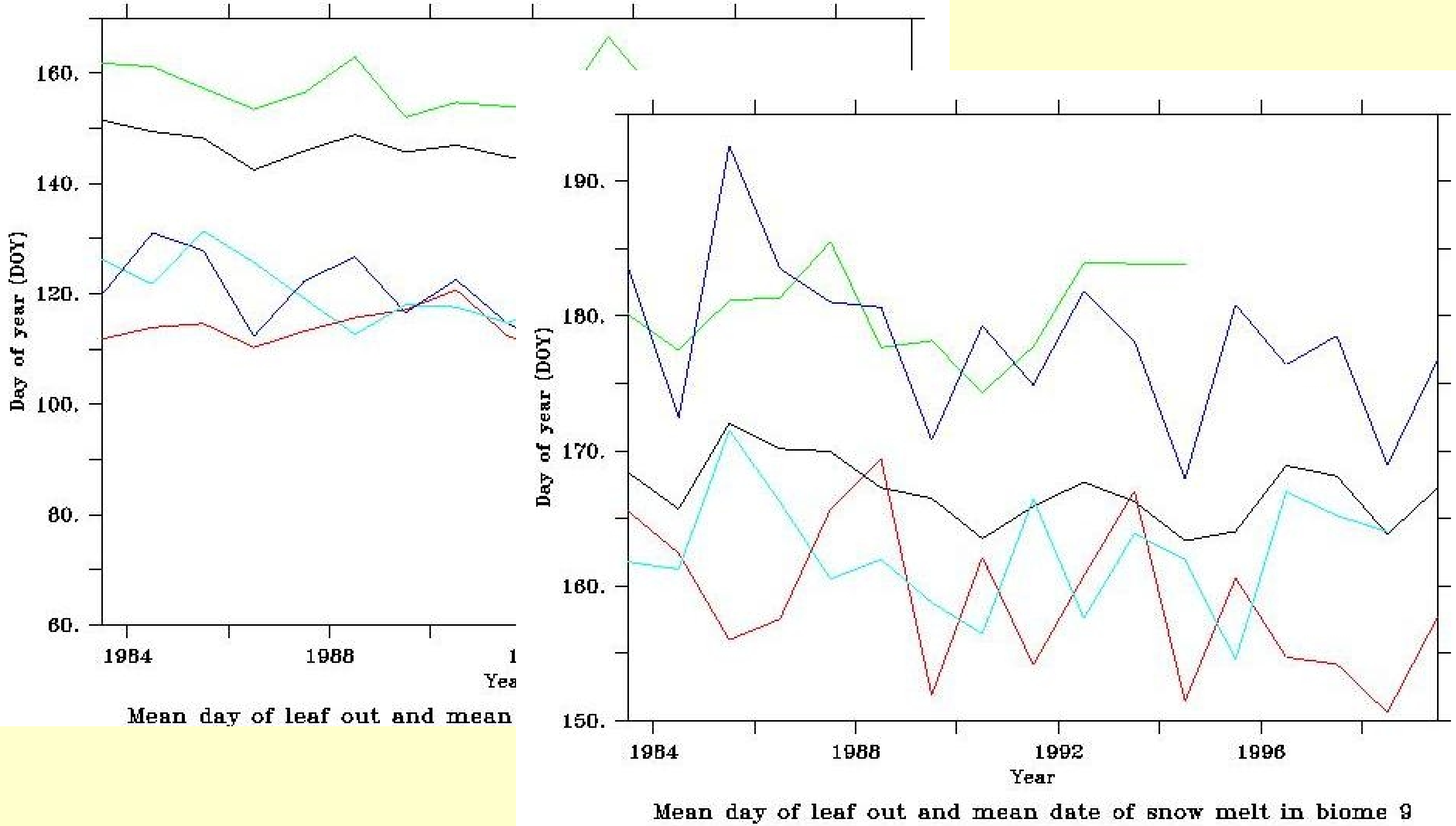
- Fit models on nine years
- Test models on remaining 10th year

- Avoids overfitted models and high prediction errors

- Mean absolute error in leaf out predictions over ten years: 4-10 days

- Nearly as small as the error of a model on the year it was determined from

Mean leaf out date

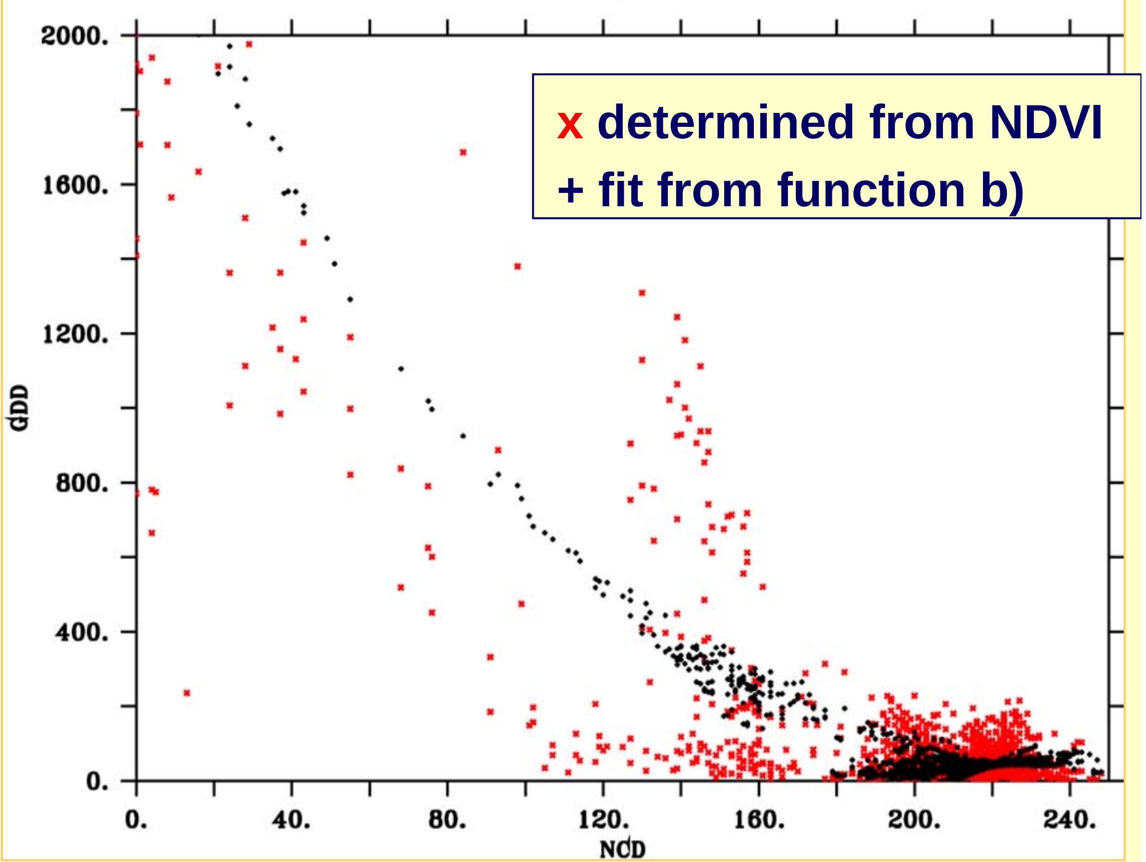


GDD-NCD relationships

- **NCD and GDD at budburst (method 1) for biome 9 (red crosses) in 1984 and fit from function b) (black pluses) using mean winter temperature**

- **explained variance 79%**

NCD and GDD at budburst for biome 9



$$\mathbf{GDD = (8301 - 32.30 \cdot T) + (-29510 + 115.4 \cdot T) \cdot \exp(-(0.0072 - 0.000006 \cdot T) \cdot NCD)}$$

CLASSIC Climate and Land Surface Systems Interaction Centre

University of Leicester