



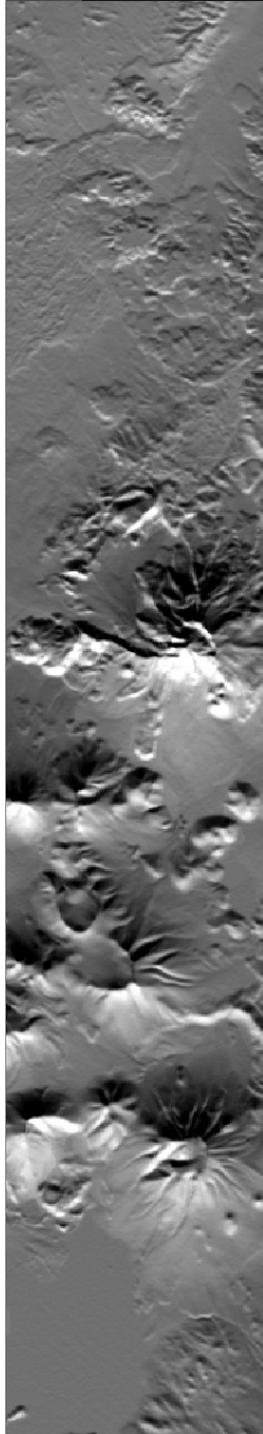
CAQSI 2018

27-28-29 mars 2018, INRA Clermont Ferrand

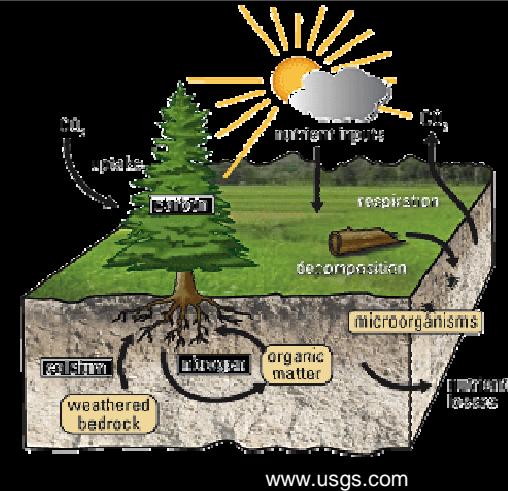
Etudier les variations spatiales de NDVI pour caractériser les contraintes environnementales limitant la vitalité des forêts de montagne et de Méditerranée

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I. Seynave, J.C. Gégout

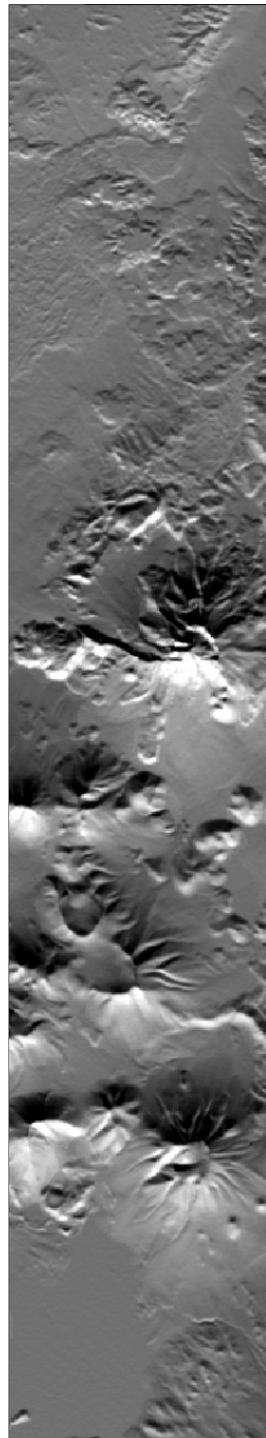
UMR SILVA Nancy, UMR DYNAFOR Toulouse



Contexte général

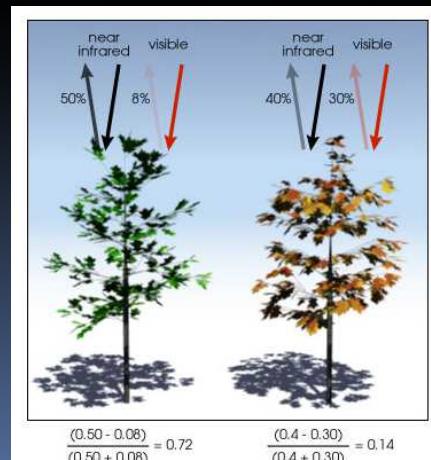


- Relations productivité/ facteur du milieu largement étudiées en forêt (croissance en hauteur (IF)/croissance radiale) (Curt 2001, Seynave 2005, Berges 2005, Charru 2010, Vallet 2016, ...)
- Contraintes liées au comportement en mélanges, effets de la structure => des travaux ciblés (souvent 1 essence, peuplement pur, équienne, ...)
- Problème de disponibilité de données
- Peu d'études à l'échelle des écosystèmes
- D'autres approches possibles: données satellites

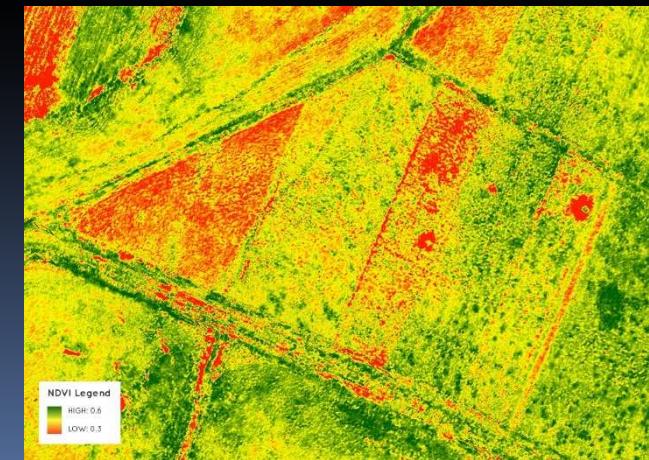


L'indice NDVI

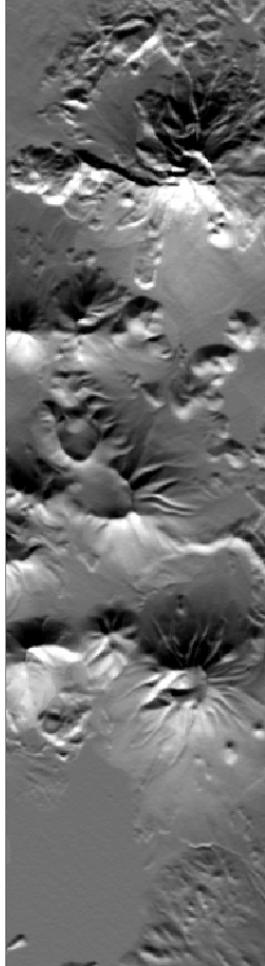
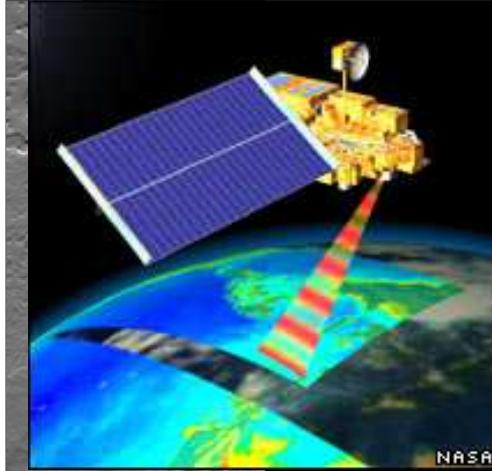
- Indice de végétation normalisé (Rouse, 1973; Tucker et al., 1985)
- ≠ réflectances mesurées dans les bandes spectrales rouge et proche infrarouge $NDVI = (PIR-R)/(PIR+R)$
- Traduit la biomasse photosynthétiquement active, sensible à la vigueur et à la quantité de la végétation.
- Lié à la productivité (Wang 2004, Maselli 2006)



<https://earthobservatory.nasa.gov/>



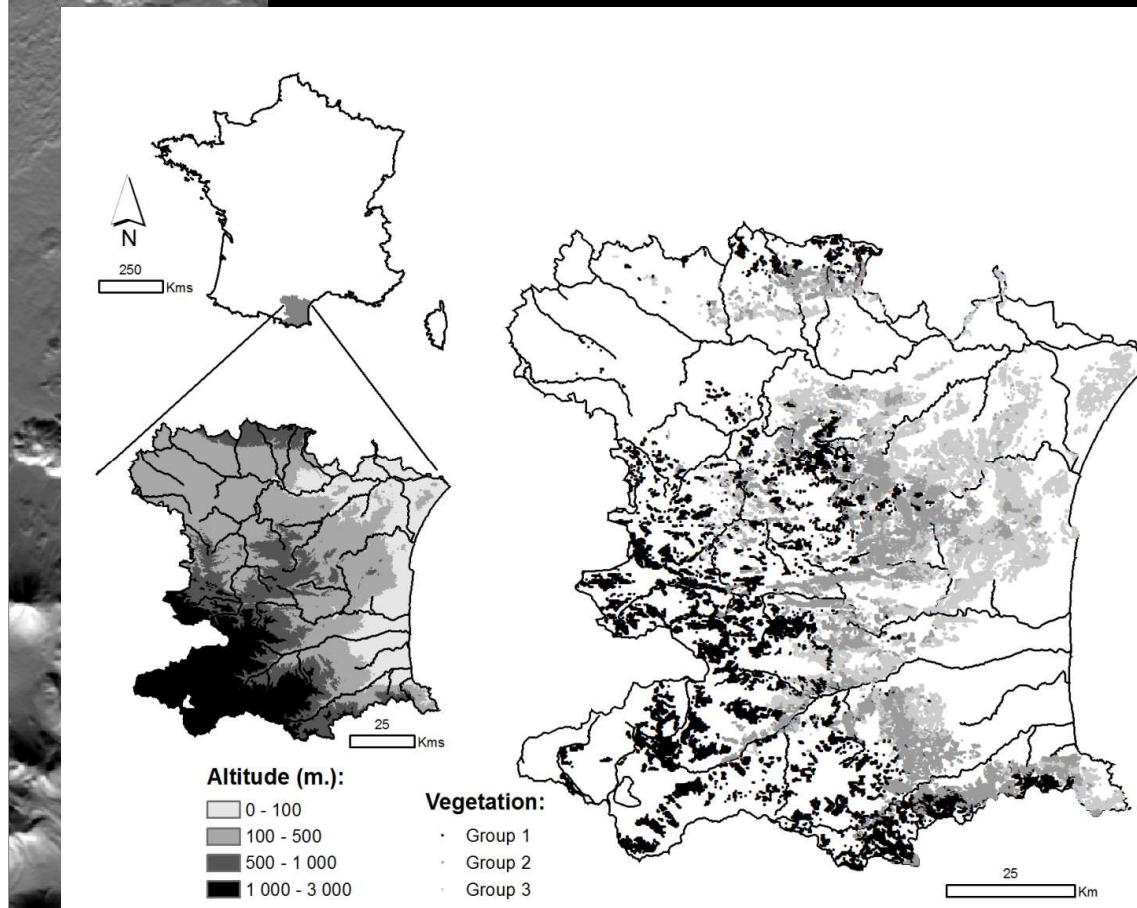
<https://www.precisionmapper.com>



L'indice NDVI

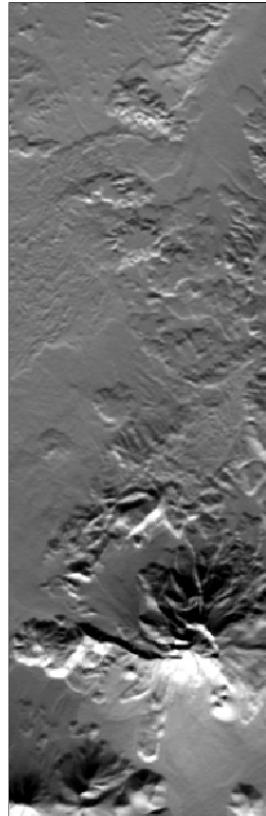
- Réponse végétation au changement climat via NDVI très étudié (Guo et al., 2014, Yan 2012, ...)
- Augmentation de NDVI montrée en région tempérée (Meng et al., 2011; Yan et al., 2012, ...)
- Plupart des études : T, P, large échelle, large résolution, échelle du groupe fonctionnel ...
- Difficulté à démêler les changements d'occupation du sol des effets environnementaux
- **Objectif** : évaluer les facteurs environnementaux corrélés variations spatiales de NDVI, \neq peuplements, zone montagne/méditerranéenne

Domaine de l'étude



	Vegetation groups	Vegetation units	n
Group 1 n=(900)	High forest of <i>Pinus uncinata</i>	72	
	High forest of <i>Abies alba</i>	16	
	High forest of <i>Pinus sylvestris</i>	50	
	High forest of <i>Fagus sylvatica</i>	95	
	<i>Fagus sylvatica</i> coppice	81	
	<i>Castanea sativa</i> coppice	77	
Group 2 n=(312)	<i>Quercus</i> sp. Coppice	216	
	Garrigue maquis with <i>Quercus pubescens</i>	78	
	High forest of <i>Pinus nigra</i>	23	
	<i>Quercus ilex</i> coppice	329	
Group 3 n=(317)	Garrigue maquis with <i>Quercus ilex</i> suber	393	
	High forest of <i>Quercus</i> suber	69	
	Garrigue maquis non wooded	872	
	High forest of <i>Pinus pinaster</i>	24	
	High forest of <i>Pinus halepensis</i>	51	

- Aude, PO (10200 km²)
- Forêts/maquis-garrigue, 3 échelles : toute végétation, 3 groupes phéno, 15 peuplements IGN

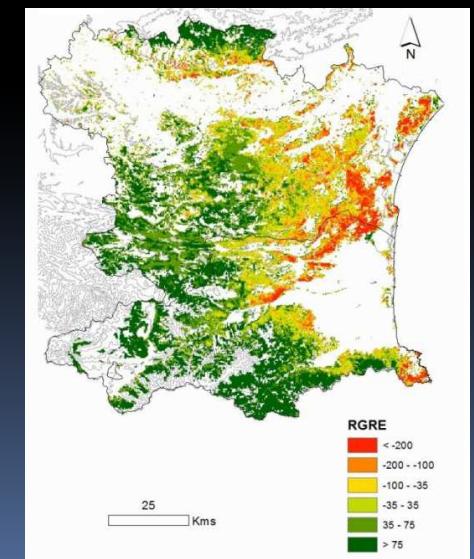
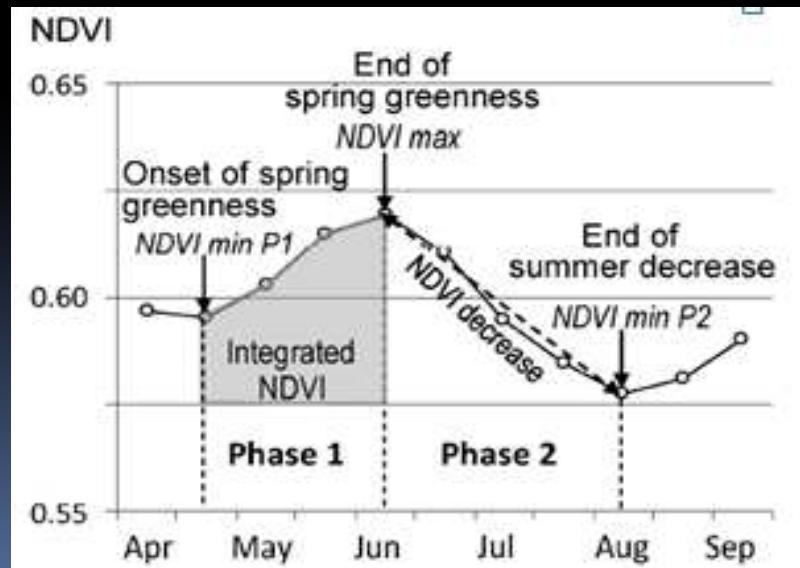
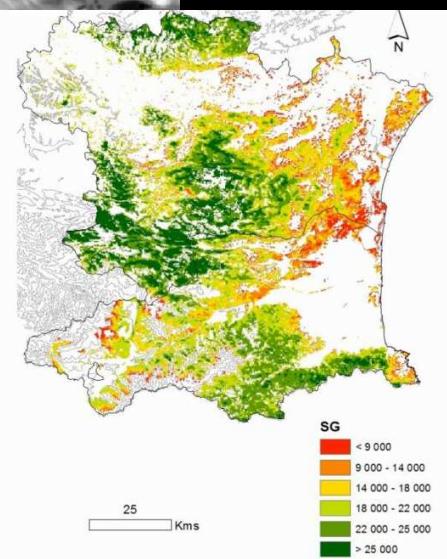


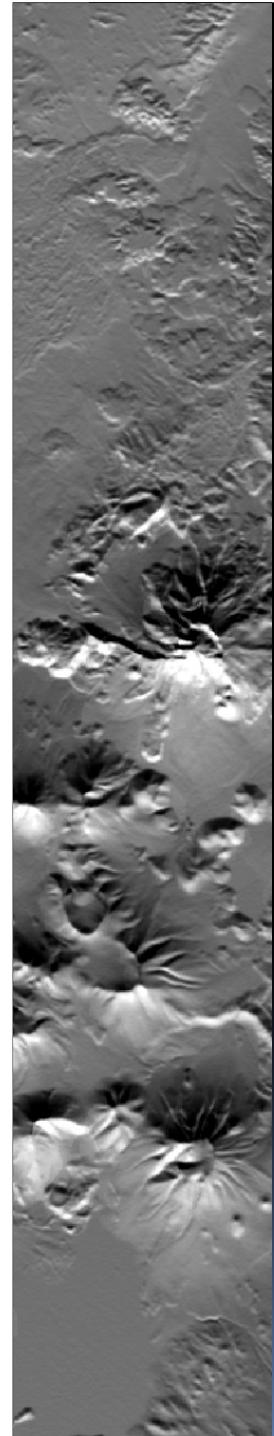
Les indices NDVI

➤ 2 indices NDVI, /an, 2000-2012 :

- Spring Greenness (SG): somme NDVI printemps
- Relative Greenness Index (RGRE, contrainte estivale):

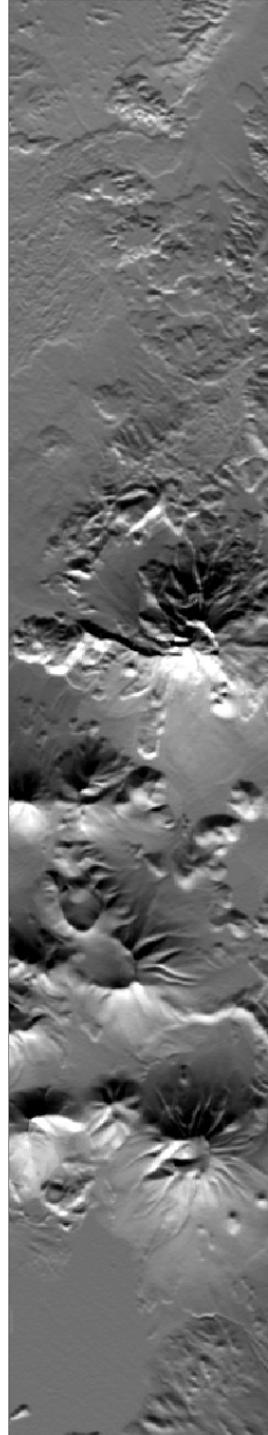
$$\text{Annual RGRE} = (NDVI_{min\ P2} - NDVI_{min\ P1}) / (NDVI_{max} - NDVI_{min\ P1})$$





Les variables environnementales

- Energie reçue : 7 variables
 - Températures (min, moy, max)
 - ETP, ETR,
 - cosinus de l'exposition
- Eau disponible : 11 variables
 - précipitations
 - Bilan hydrique climatique (P-ETP)
 - Réserve Utile Maximale
 - Bilan hyd. édaphique; RU, REW, AI, DE, SWD
 - Drainage latéral: TWI
 - Engorgement (temporaire, permanent)
- Nutrition des plantes: 2 variables
 - pH
 - C/N



Méthodologie

2 indices NDVI
SG + RGRE

20 indices
différentes saisons
46/59 prédicteurs

Filtrage, extraction maille 1 km
2649 cellule, 12 ans

Régression linéaire multiple
3 échelles

Comparaison
des indices

Analyse
multivariée

Choix des prédicteurs, relations SG/RGRE

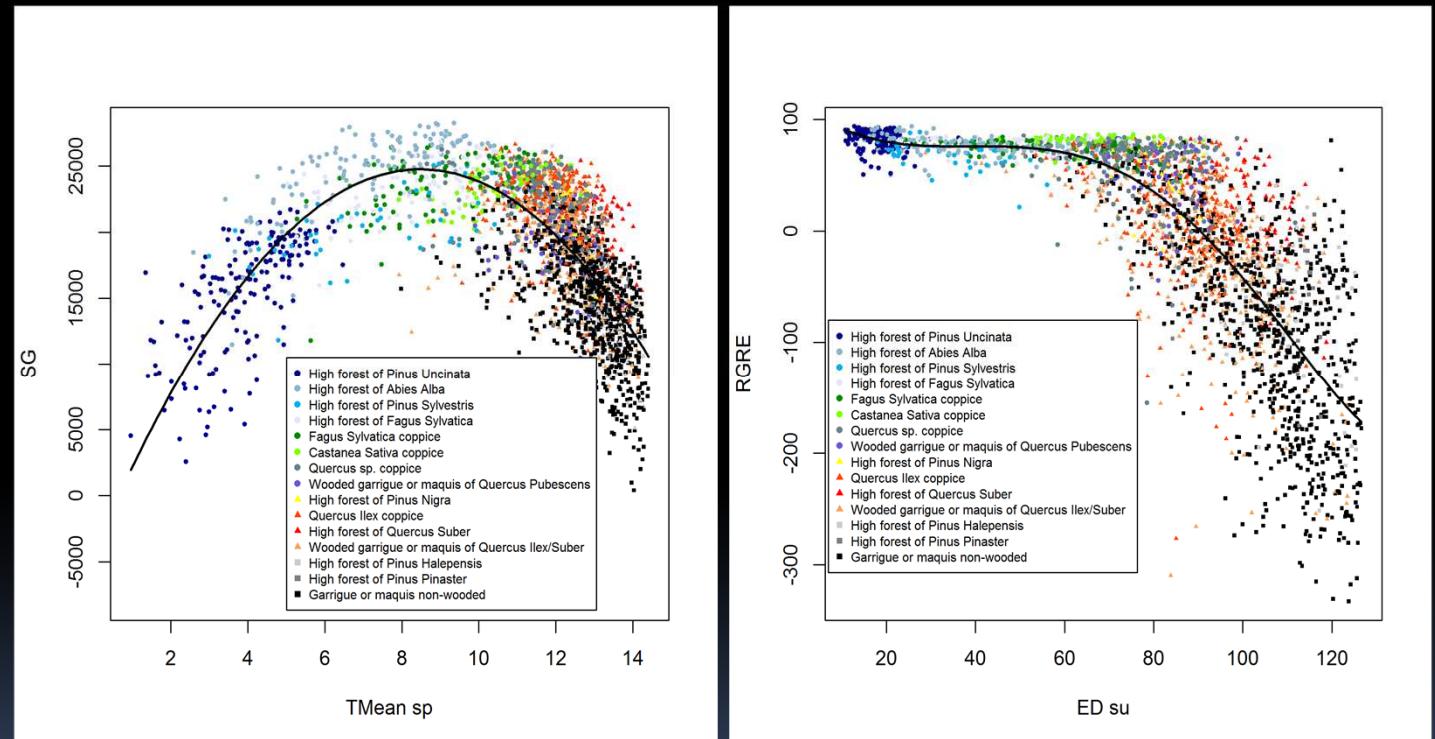
Résultats : comparaison des indices

	SG	n	Tmean	Tmin	Tmax	SR	PET	AET	Cosa	P	CWB	SWC	AI	ED	REW	SWD	SWHC	TWI	TW	PW	pH	C/N
All		34168	53(Sp)	51(Sp)	35(Yr)	06(Gs)	48(Gs)	25(Gs)	1	29(Gs)	39(Gs)	20(Sp)	37(Yr)	35(Yr)	32(Yr)	28(Gs)	1	19	26	14	36	4
Group 1		11544	61(Sp)	60(Sp)	55(Gs)	10(Gs)	61(Sp)	57(Sp)	1	54(Yr)	60(Yr)	04(Gs)	44(Yr)	23(Yr)	28(Yr)	10(Gs)	4	0	10	6	5	48
Group 2		10313	25(Sp)	20(Sp)	17(Yr)	02(Yr)	19(Gs)	07(Sp)	1	09 (Sp)	12 (Sp)	04 (Sp)	10(Gs)	12 (Yr)	08 (Yr)	07(Gs)	1	17	28	16	33	5
Group 3		12311	39(Yr)	36(Yr)	21(Yr)	03(Gs)	31(Yr)	21(Gs)	0	26(Gs)	30(Gs)	15(Gs)	28(Yr)	30 (Yr)	25 (Yr)	23(Yr)	1	9	14	13	16	3
Group 1	High forest of <i>Pinus uncinata</i>	2236	42(Gs)	41 (Gs)	36 (Yr)	02 (Gs)	54 (Sp)	55 (Sp)	0	49 (Yr)	65 (Yr)	15 (Sp)	39 (Yr)	11 (Yr)	16 (Gs)	15 (Sp)	18	6	1	1	1	11
	High forest of <i>Abies alba</i>	1638	58 (Sp)	58 (Sp)	63 (Sp)	07 (Sp)	60 (Sp)	61 (Sp)	0	64 (Yr)	66 (Yr)	04 (Sg)	39 (Yr)	32 (Gs)	33 (Gs)	09 (Gs)	2	14	2	2	18	57
	High forest of <i>Pinus sylvestris</i>	650	42 (Gs)	42 (Sp)	52 (Gs)	22 (Gs)	58 (Sp)	54 (Sp)	6	47 (Yr)	52 (Gs)	11 (Gs)	36 (Gs)	35 (Gs)	36 (Yr)	18 (Gs)	4	2	12	3	25	57
	High forest of <i>Fagus sylvatica</i>	1209	42 (Sp)	39 (Sp)	48 (Gs)	17 (Sp)	33 (Sp)	30 (Sp)	4	46 (Yr)	53 (Yr)	14 (Sp)	26 (Yr)	23 (Gs)	25 (Yr)	12 (Sp)	26	8	2	12	13	29
	<i>Fagus sylvatica</i> coppice	1092	35 (Sp)	32 (Sp)	40 (Gs)	06 (Sp)	47 (Gs)	44 (Sp)	5	50 (Yr)	58 (Sp)	16 (Sp)	27 (Yr)	20 (Gs)	22 (Gs)	17 (Sp)	36	19	2	1	4	33
	<i>Castanea sativa</i> coppice	1001	25 (Gs)	25 (Gs)	09 (Gs)	19 (Gs)	04 (Gs)	22 (Gs)	2	25 (Sp)	17 (Sp)	12 (Sp)	24 (Gs)	22 (Gs)	19 (Gs)	15 (Gs)	9	1	12	5	4	6
	<i>Quercus</i> sp. Coppice	2808	28 (Gs)	29 (Yr)	26 (Yr)	02 (Sp)	18 (Yr)	09 (Sp)	0	05 (Sp)	10 (Yr)	04 (Sp)	07 (Sp)	08 (Sp)	07 (Yr)	05 (Gs)	2	4	6	2	7	6
	Garrigue/maquis <i>Quercus pubescens</i>	910	26 (yr)	25 (Sp)	23 (Yr)	01 (Gs)	13 (Yr)	09 (Yr)	2	12 (gs)	11 (Yr)	03 (Gs)	09 (Yr)	08 (Yr)	08 (Yr)	05 (Sp)	8	4	1	1	1	13
Group 2	High forest of <i>Pinus nigra</i>	299	67 (Sp)	68 (Sp)	25 (Yr)	23 (Sp)	12 (Gs)	31 (Yr)	6	17 (Yr)	18 (Yr)	21 (Gs)	16 (Sp)	17 (Sp)	14 (Sg)	19 (Sp)	9	19	34	13	12	1
	<i>Quercus ilex</i> coppice	4277	21 (Sp)	17 (Sp)	19 (Gs)	04 (Gs)	14 (Gs)	07 (Sp)	0	06 (Sp)	07 (Yr)	03 (Sp)	04 (Sp)	05 (Sp)	04 (Sp)	04 (Yr)	2	11	11	1	18	2
	Garrigue/maquis <i>Quercus ilex</i> /suber	4840	34 (Yr)	34 (Sp)	22 (Yr)	03 (Gs)	18 (Sp)	14 (Gs)	1	18 (Yr)	21 (Yr)	12 (Gs)	19 (Yr)	20 (Sg)	17 (Yr)	15 (Yr)	2	11	12	14	16	2
	High forest of <i>Quercus suber</i>	897	26 (Gs)	17 (Sp)	33 (Yr)	14 (Sp)	32 (Gs)	15 (Sp)	6	16 (Yr)	23 (Yr)	11 (Sp)	20 (Yr)	24 (yr)	17 (Sp)	18 (Gs)	36	32	2	6	12	21
Group 3	Garrigue/maquis non wooded	11336	35 (Yr)	33 (Sp)	16 (Yr)	02 (Gs)	28 (Gs)	22 (Gs)	1	25 (Gs)	29 (Gs)	17 (Gs)	28 (Yr)	29 (Gs)	25 (Yr)	22 (Sp)	3	15	31	15	33	5
	High forest of <i>Pinus pinaster</i>	312	56 (Yr)	54 (Yr)	48 (Yr)	08 (Sp)	19 (Yr)	33 (Sp)	41	36 (Yr)	40 (Yr)	27 (Sp)	35 (Sp)	34 (Sp)	33 (Sp)	32 (Gs)	24	3	23	12	4	3
	High forest of <i>Pinus halepensis</i>	663	31 (Sp)	25 (Gs)	15 (Gs)	05 (Gs)	20 (Gs)	12 (Gs)	1	18 (Gs)	24 (Yr)	06 (Sp)	16 (Yr)	17 (Yr)	13 (Yr)	15 (Gs)	4	1	8	6	4	3

	RGRE	n	Tmean	Tmin	Tmax	SR	PET	AET	Cosa	P	CWB	SWC	AI	ED	REW	SWD	SWHC	TWI	TW	PW	Soil nutrition	
All		34168	34 (Sp)	34 (Yr)	23 (Yr)	05 (Yr)	34 (Su)	42 (Su)	2	32 (Su)	36 (Su)	33 (Sp)	42 (Su)	45 (Su)	36 (Sp)	36 (Sp)	1	18	16	7	38	4
Group 1		11544	19 (Sp)	18 (Yr)	18 (Yr)	02 (Yr)	17 (Gs)	15 (Yr)	1	14 (Su)	17 (Su)	08 (Su)	15 (Su)	17 (Yr)	14 (Gs)	13 (Su)	3	4	1	1	13	11
Group 2		10313	10 (Gs)	09 (Yr)	05 (Yr)	02 (Yr)	08 (Yr)	16 (Su)	1	14 (Su)	17 (Su)	09 (Gs)	17 (Su)	18 (Su)	13 (Gs)	13 (Sp)	3	6	19	8	19	3
Group 3		12311	15 (Gs)	16 (Gs)	05 (Yr)	05 (Su)	16 (Su)	26 (Su)	1	21 (Su)	24 (Su)	23 (Sp)	27 (Su)	27 (Su)	25 (Sp)	22 (Sp)	2	10	10	7	16	4
Group 1	High forest of <i>Pinus uncinata</i>	2236	12 (Gs)	12 (Gs)	10 (Gs)	03 (Yr)	15 (Gs)	17 (Gs)	3	15 (Yr)	08 (Yr)	08 (Gs)	13 (Yr)	09 (Su)	08 (Su)	08 (Sp)	9	2	5	2	8	6
	High forest of <i>Abies alba</i>	1638	14 (Su)	14 (Gs)	13 (Gs)	04 (Su)	12 (Sp)	11 (Yr)	0	14 (Yr)	14 (Yr)	08 (Su)	11 (Su)	11 (Su)	12 (Yr)	12 (Gs)	6	8	5	6	9	9
	High forest of <i>Pinus sylvestris</i>	650	27 (Su)	27 (Su)	26 (Su)	17 (Yr)	20 (Yr)	21 (Sp)	4	22 (Gs)	22 (Gs)	13 (Su)	22 (Yr)	19 (Gs)	22 (Yr)	15 (Gs)	3	5	4	5	11	24
	High forest of <i>Fagus sylvatica</i>	1209	05 (Gs)	06 (Gs)	06 (Gs)	06 (Su)	04 (Gs)	09 (Gs)	4	08 (Sp)	07 (Sp)	07 (Sp)	08 (Sp)	08 (Sp)	07 (Sp)	05 (Gs)	6	6	4	3	6	5
	<i>Fagus sylvatica</i> coppice	1092	19 (Gs)	18 (Gs)	21 (Gs)	05 (Yr)	15 (Gs)	16 (Su)	3	17 (Su)	18 (Su)	07 (Su)	18 (Su)	20 (Yr)	14 (yr)	13 (Gs)	6	9	6	5	19	18
	<i>Castanea sativa</i> coppice	1001	15 (Sp)	13 (Gs)	13 (Gs)	05 (Gs)	07 (Yr)	13 (Gs)	5	14 (Gs)	15 (Gs)	11 (Yr)	11 (Sp)	12 (Su)	11 (Yr)	11 (Yr)	1	11	27	3	27	13
	<i>Quercus</i> sp. Coppice	2808	08 (Gs)	08 (Sp)	08 (Su)	02 (Su)	08 (Su)	08 (Su)	1	08 (Su)	08 (Su)	05 (Su)	11 (Gs)	11 (Gs)	10 (Gs)	08 (Gs)	1	9	3	2	1	2
	Garrigue/maquis <i>Quercus pubescens</i>	910	06 (Gs)	06 (Gs)	06 (Gs)	02 (Gs)	07 (Su)	12 (Su)	7	16 (Su)	15 (Su)	04 (Gs)	11 (Su)	11 (Su)	06 (Sp)	13 (Su)	16	4	3	3	5	15
Group 2	High forest of <i>Pinus nigra</i>	299	30 (Gs)	29 (Gs)	20 (Su)	26 (Gs)	12 (Yr)	22 (Gs)	23	24 (Su)	19 (Su)	19 (Yr)	21 (Su)	19 (Su)	15 (Su)	21 (Su)	15	1	29	12	17	17
	<i>Quercus ilex</i> coppice	4277	07 (Gs)	05 (Gs)	07 (Gs)	03 (Gs)	08 (Gs)	07 (Gs)	1	10 (Su)	12 (Su)	04 (Gs)	11 (Su)	12 (Su)	10 (Gs)	10 (Gs)	3	14	5	8	1	6
	Garrigue/maquis <i>Quercus ilex</i> /suber	4840	16 (Gs)	18 (Gs)	09 (Yr)	04 (Gs)	15 (Gs)	24 (su)	1	19 (Gs)	22 (Su)	18 (Gs)	25 (Gs)	26 (Su)	23 (Gs)	21 (Gs)	3	14	15	4	18	4
	High forest of <i>Quercus suber</i>	897	09 (Su)	14 (Su)	10 (Su)	06 (Gs)	05 (Su)	20 (su)	3	19 (Su)	15 (Gs)	04 (Yr)	18 (Su)	14 (Su)	09 (Sp)	13 (Gs)	4	1	1	1	1	16
Group 3	Garrigue/maquis non wooded	11336	17 (Yr)	18 (Su)	06 (Yr)	04 (Su)	17 (Su)	29 (Su)	1	23 (Su)	26 (Su)	27 (Gs)	30 (Su)	31 (Su)	28 (Gs)	25 (Yr)	5	7	21	8	22	4
	High forest of <i>Pinus pinaster</i>	312	20 (Su)	21 (Sp)	25 (Su)	18 (Yr)	15 (Yr)	15 (Yr)	13	15 (Su)	15 (Su)	12 (Gs)	17 (Sp)	15 (Su)	17 (Yr)	17 (Yr)	12	16	18	7	14	13
	High forest of <i>Pinus halepensis</i>	663	10 (Gs)	15 (Gs)	18 (Su)	10 (Gs)	12 (Yr)	19 (Su)	2	15 (Su)	16 (Su)	19 (Yr)	19 (Su)	20 (Su)	19 (Gs)	17 (Yr)	5	9	16	9	11	2

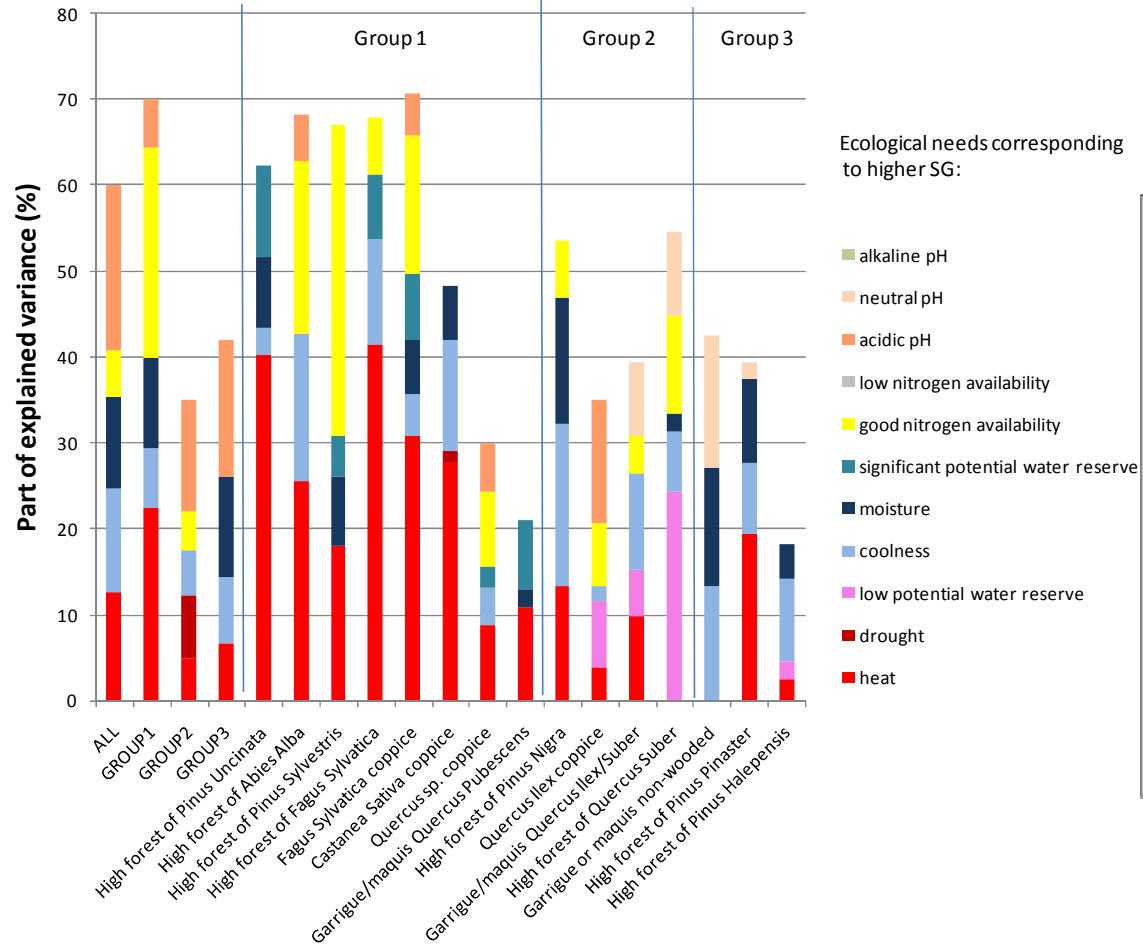
Réponses le long des gradients écologiques

- Températures minimum printemps pour SG
- Déficit hydrique estival pour RGRE

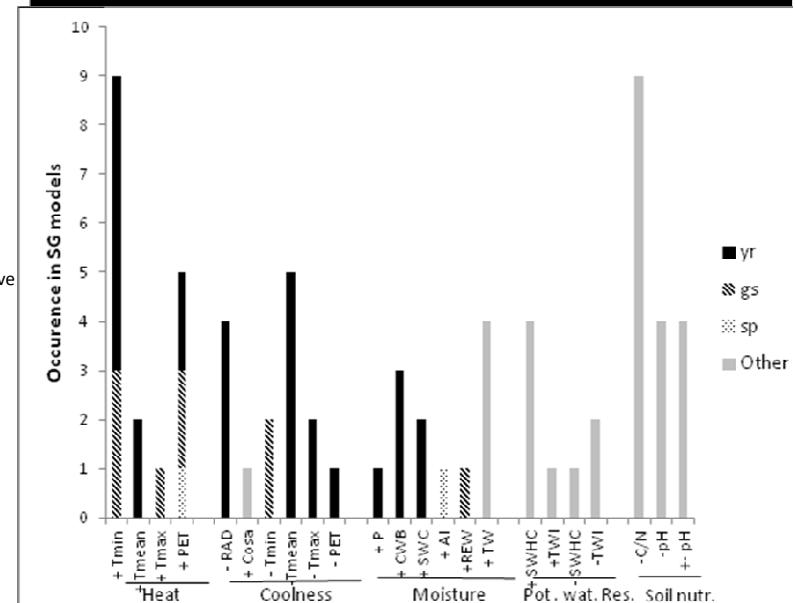


- Valeur seuil de 8°C pour température printemps et -70 mm pour le déficit hydrique estival
- Seuils communs différents peuplements étudiés

Facteurs environnementaux corrélés SG

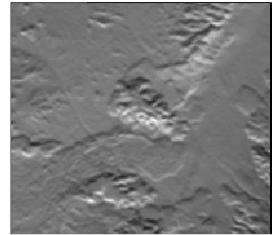


Ecological needs corresponding to higher SG:

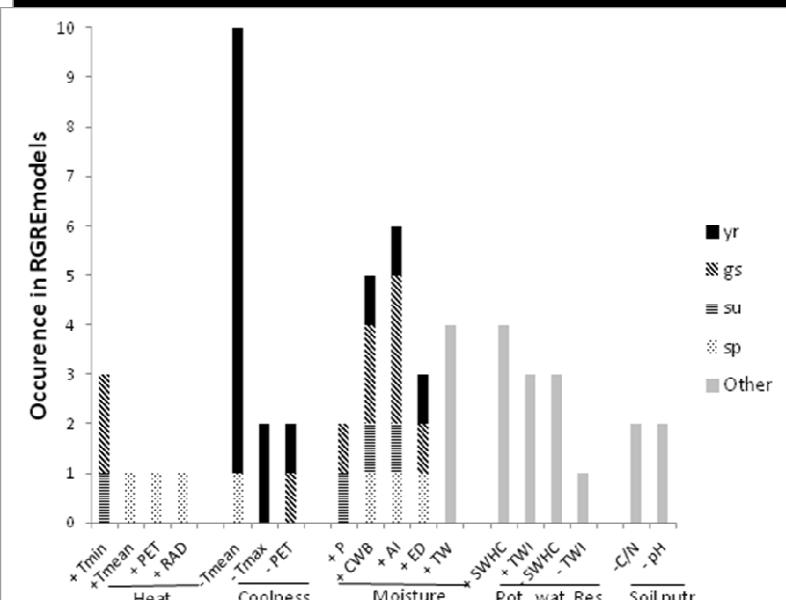
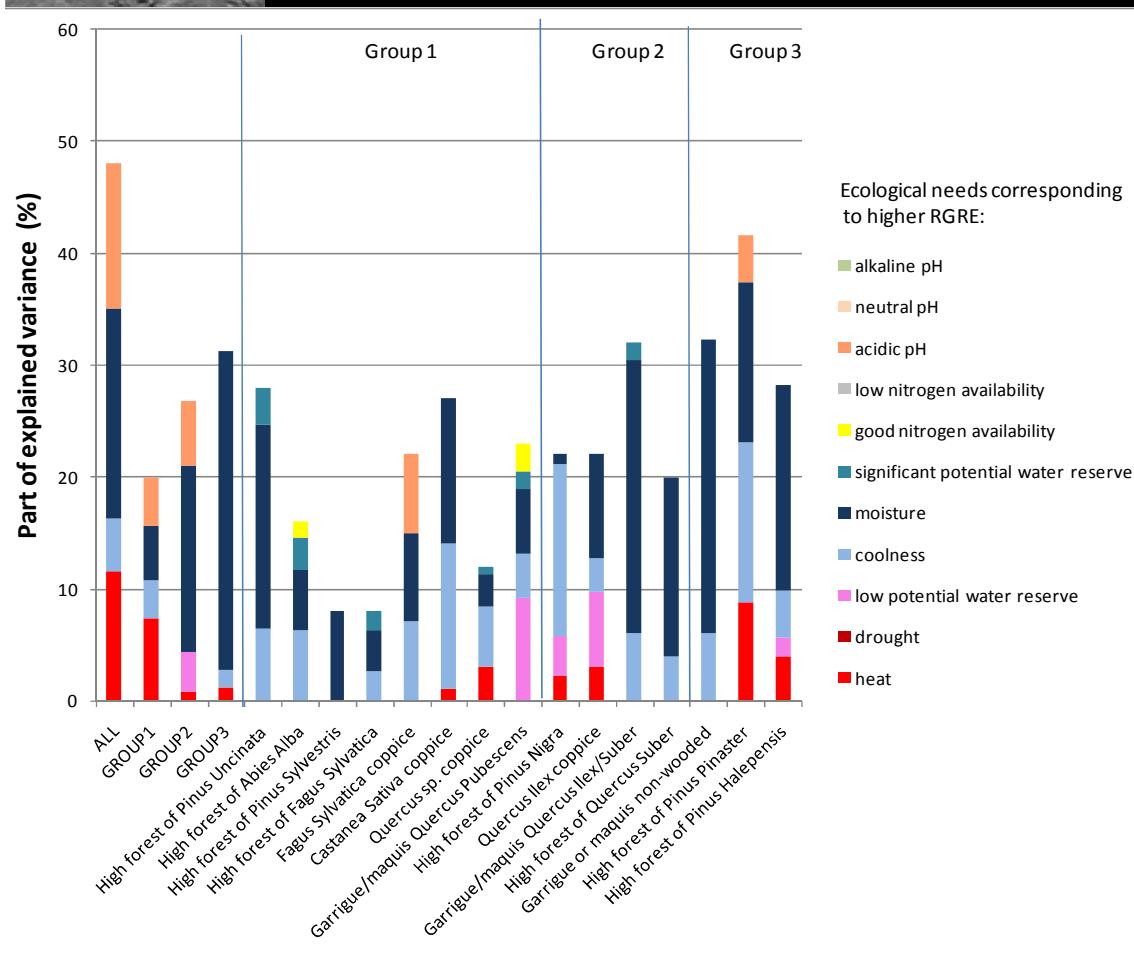


15 peuplements IFN

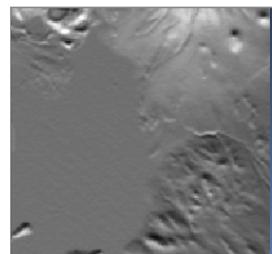
➤ SG + important quand Tmin élevées, T moy-max faibles, humide, N disponible et pH acide-neutre



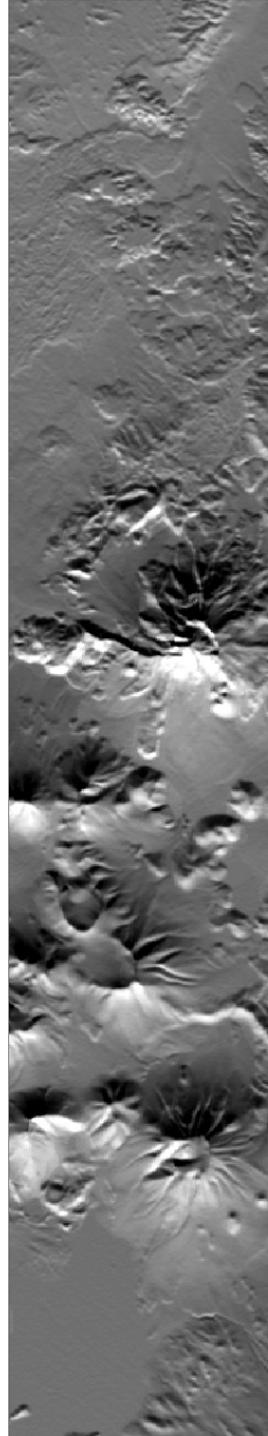
Conclusion-discussion



15 peuplements IFN

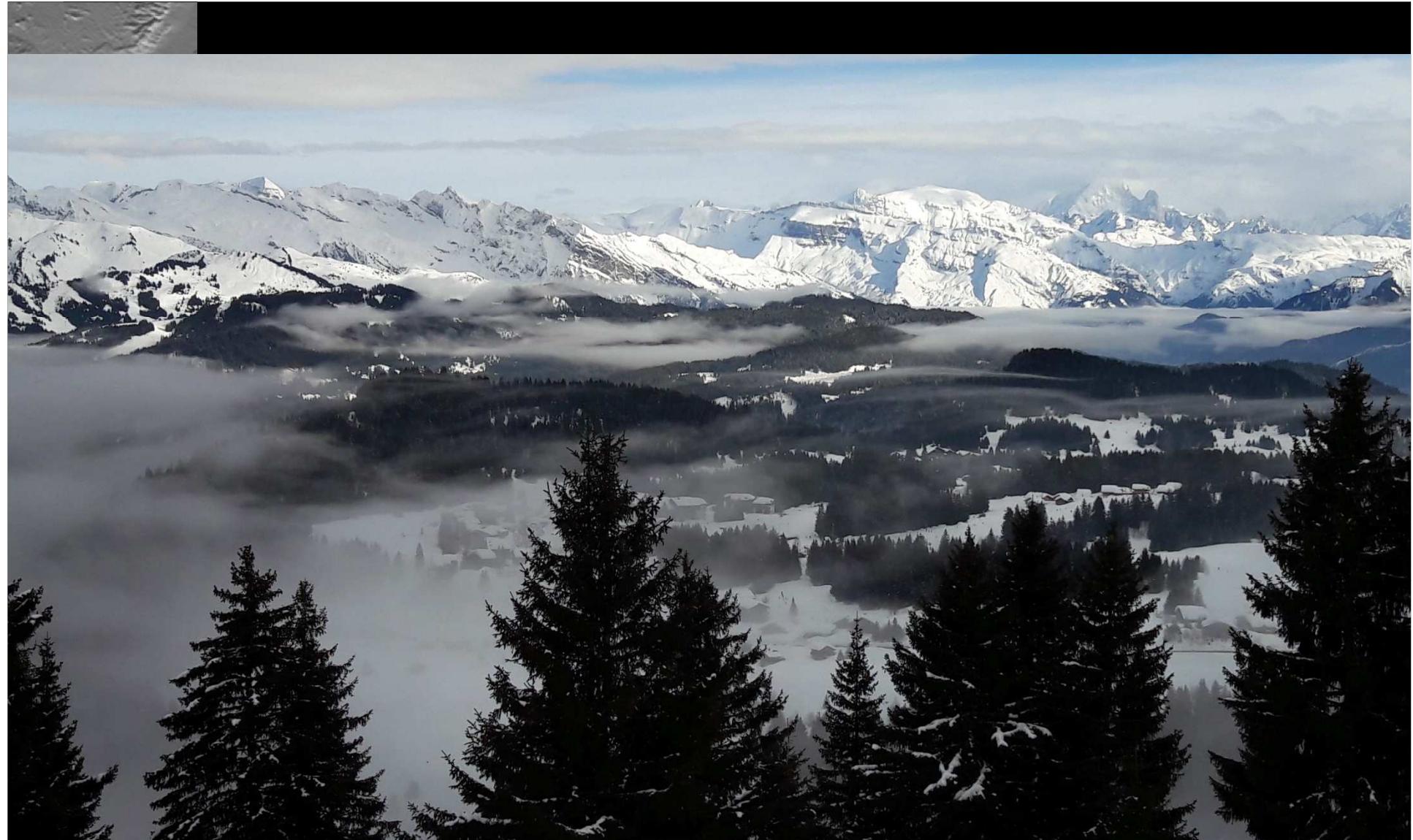


➤ RGRE + important quand Temp faibles et eau dispo, voire pH acides



Conclusion

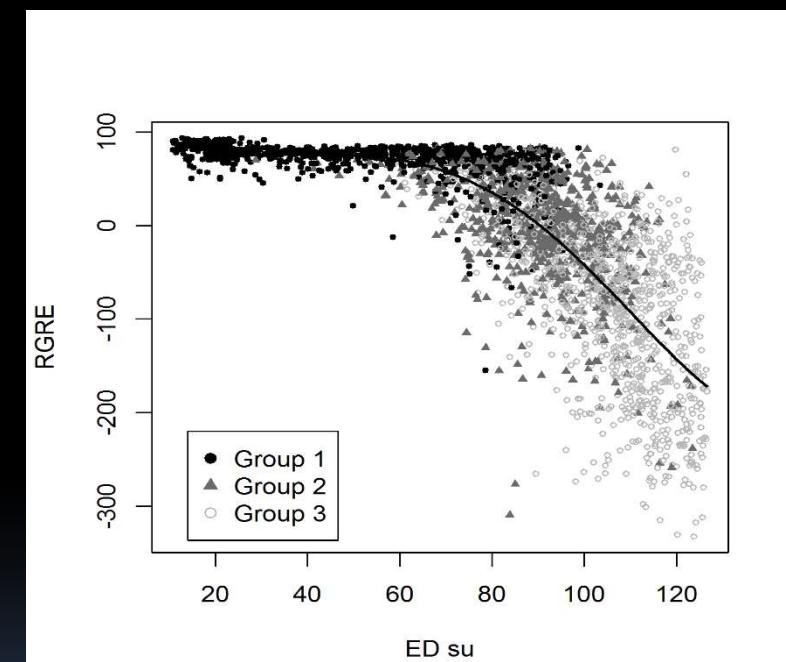
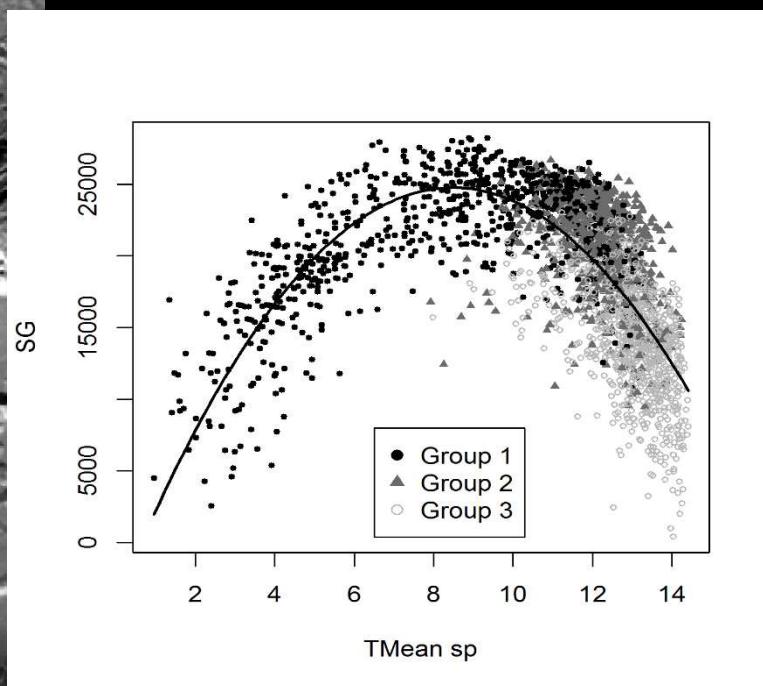
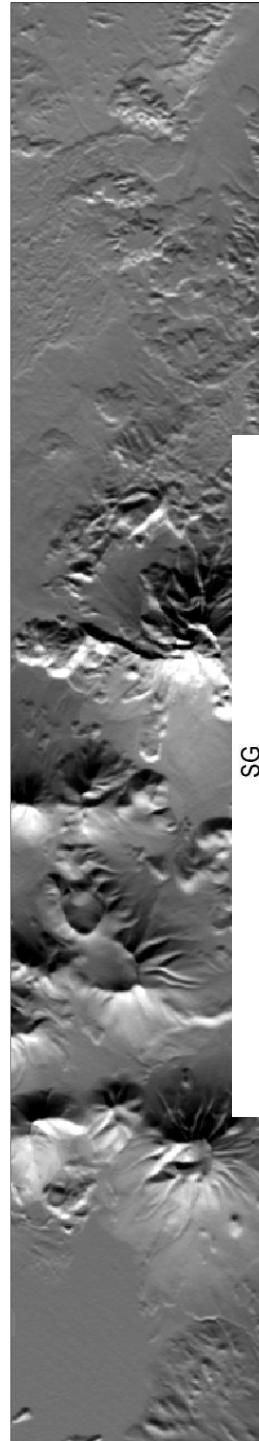
- Focalisé zones naturelles non perturbées => rôle facteurs envt, perturbations biotiques possible
- Jusqu'à 70 % de la variance SG expliquée, 48% pour RGRE, aspect multifactoriel
- T°C + important mais sens différent selon saison, échelle, et peuplement
- Eau est d'autant plus importante qu'elle est limitante (saison, peuplement), difficulté à prendre en compte
- Importance des propriétés du sol (aspects hydriques, nutritionnels)
- Un transfert de dynamique de végétation (altitude : contrainte printanière, plaine, contrainte estivale)
- Permet d'évaluer les conséquences possibles du changement de climat en cours



Merci de votre attention ...

	VARIABLE	ABBREVIATION	DEFINITION
Energy	Mean temperature (°C)*	Tmean	Mean monthly temperatures
	Minimum temperature (°C)*	Tmin	Minimum monthly temperatures
	Maximum temperature (°C)*	Tmax	Maximum monthly temperatures
	Solar radiation (J/cm ²)*	RAD	Mean monthly solar radiation
	Potential evapotranspiration (mm)*	PET	$PET_t = (\alpha * (RAD_t/D_t * 0.2388 + 50)) * (T_t/(T_t+15))$ With $\alpha = 0.37$ for February, else 0.4 D = number of days
	Actual evapotranspiration (mm)*	AET	If $P_t \geq PET_t$ then $AET_t = PET_t$ If $P_t \leq PET_t$ then $AET_t = SWC_{t-1} + P_t - SWC_t$
	Cosine of aspect	Cosa	$Cosa = \cos(\text{aspect})$
Available water	Precipitation (mm)*	P	Sum of mean monthly precipitation
	Climatic water balance (mm)*	CWB	$CWB_t = P_t - PET_t$
	Soil water holding capacity (mm)	SWHC	Amount of water that can be stored in the soil
	Soil water content (mm)*	SWC	If $P_t \geq PET_t$ then $SWC_t = \min(SWC_{t-1} + CWB_t \text{ and } SWHC, P_t)$ If $P_t \leq PET_t$ then $SWC_t = SWC_{t-1} * \exp((CWB_t)/SWHC)$
	Relative extractable water (mm)*	REW	$REW_t = SWC_t / SWHC$
	Aridity index (mm)*	AI	$AI_t = AET_t / PET_t$
	Evapotranspiration Deficit (mm)*	ED	$ED_t = PET_t - AET_t$
	Soil water deficit (mm)*	SWD	$SWD_t = 0.4 * SWHC - SWC_t$
	Topographic Wetness Index	TWI	$TWI = \ln(a/\tan b)$ $a = \text{upslope area}, b = \text{slope in radians}$
	Temporary waterlogging	TW	Bioindication with flora
	Permanent waterlogging	PW	Bioindication with flora
Soil nutrition	Soil richness	pH	Bioindication with flora
	Nitrogen availability	C/N	Bioindication with flora

Contexte général



SG	Variable 1	Variable 2	Variable 3	Variable 4	Variable 5	Variable 6
All	+Tmin gs	-RAD su	-PET gs	+TW	+pH	-CN
Group 1	+Tmin gs	+PET yr	-RAD yr	+AI yr	-CN	-pH
Group 2	+Tmean gs	-RAD yr	+pH	-CN		
Group 3	+Tmin gs	+P yr	+TW	+pH		
High forest of <i>Pinus uncinata</i>	+Tmin yr	+PET yr	-RAD yr	+SWHC	+TW	
High forest of <i>Abies alba</i>	+Tmin yr	-Tmax yr	+PET sp	-CN	+pH	
High forest of <i>Pinus sylvestris</i>	+PET yr	+SWHC	+TW	+AI sp	-CN	
High forest of <i>Fagus sylvatica</i>	+Tmax gs	+PET gs	-RAD yr	+Cosa	+SWHC	-CN
<i>Fagus sylvatica</i> coppice	+PET gs	-RAD yr	+TWI	+SWC yr	-CN	+pH
<i>Castanea sativa</i> coppice	+Tmin gs	-Tmax yr	-RAD yr	-REW gs		
Quercus sp. Coppice	+Tmean yr	+Tmin yr	+SWHC	-CN	-pH	
Garrigue/maquis Quercus pub.	+Tmin gs	+SWHC	+CWB yr			
High forest of <i>Pinus nigra</i>	-Tmean yr	+Tmin yr	+TW	-CN		
Quercus ilex coppice	-Tmean yr	+PET yr	-TWI	-pH	-CN	
Garrigue/maquis with Quercus ilex/suber	+Tmin gs	-TWI	-CN	+pH		
High forest of <i>Quercus suber</i>	-PET yr	-SWHC	+CWB yr	-CN	+pH	
Garrigue/maquis non wooded	-Tmin gs	+TW	+P yr	+pH		
High forest of <i>Pinus pinaster</i>	+Tmean yr	+Tmin yr	+PET sp	+SWC yr	+pH	
High forest of <i>Pinus halepensis</i>	-Tmean yr	+Tmin yr	+CWB yr	-TWI	-CN	