Land-surface processes in NWP: Vegetation and carbon

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Outlines

- Vegetation
  - Role of vegetation in NWP
  - Tiled approach and current data
  - Evolution of vegetation parametrization and practical cases
- Carbon
  - Why are we interested in carbon?
  - Parametrization and feedback from the atmosphere
  - Comparison with Jarvis approach and interaction with the atmosphere

Vegetation state affects

- Energy/water budgets
  - Evapotranspiration
  - Interception evaporation
  - Surface albedo (net radiation at the surface)
  - Aerodynamic exchange through surface roughness
- Carbon budget
  - Plant Respiration
  - photosynthesis

Vegetation role: some recaps

- **Energy balance equation**

$$(1-a)R_S^{\downarrow} + \varepsilon_g R_T^{\downarrow} - \varepsilon_g \sigma T_{sk}^4 + H + \lambda E = G$$

➔ **Albedo (a) and emissivity (ε) depend on the surface/vegetation condition**

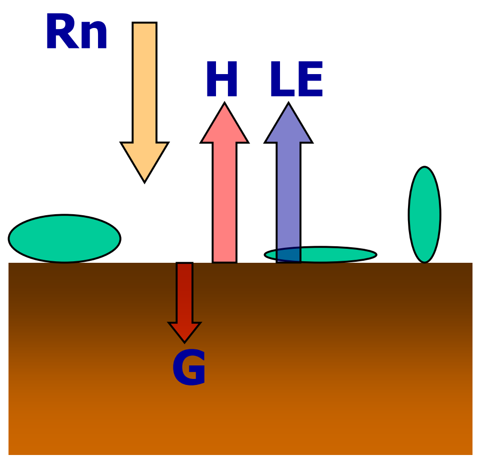


Table 3.1
Radiative Properties of Natural Surfaces[a]

Surface type	Other specifications	Albedo (a)	Emissivity (ε)
Water	Small zenith angle	0.03–0.10	0.92–0.97
	Large zenith angle	0.10–0.50	0.92–0.97
Snow	Old	0.40–0.70	0.82–0.89
	Fresh	0.45–0.95	0.90–0.99
Ice	Sea	0.30–0.40	0.92–0.97
	Glacier	0.20–0.40	
Bare sand	Dry	0.35–0.45	0.84–0.90
	Wet	0.20–0.30	0.91–0.95
Bare soil	Dry clay	0.20–0.35	0.95
	Moist clay	0.10–0.20	0.97
	Wet fallow field	0.05–0.07	
Paved	Concrete	0.17–0.27	0.71–0.88
	Black gravel road	0.05–0.10	0.88–0.95
Grass	Long (1 m) Short (0.02 m)	0.16–0.26	0.90–0.95
Agricultural	Wheat, rice, etc.	0.10–0.25	0.90–0.99
	Orchards	0.15–0.20	0.90–0.95
Forests	Deciduous	0.10–0.20	0.97–0.98
	Coniferous	0.05–0.15	0.97–0.99

[a] Compiled from Sellers (1965), Kondratyev (1969), and Oke (1978).

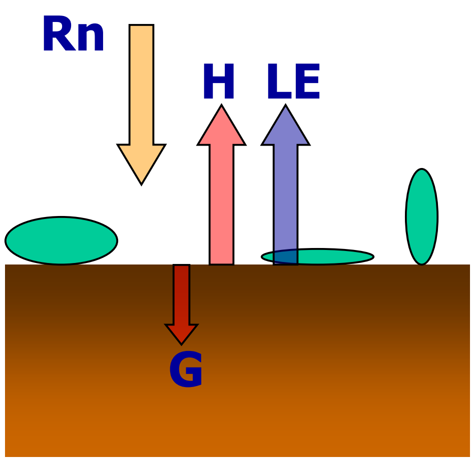
Arya, 1988

Vegetation role: some recaps

- **Energy balance equation**

$$(1-a)R_S^{\downarrow} + \varepsilon_g R_T^{\downarrow} - \varepsilon_g \sigma T_{sk}^4 + H + \lambda E = G$$

➔ Sensible heat (H) is also related to vegetation through its relative partition with LE and the aerodynamic exchange specific to surface/vegetation type



Sensible heat flux

$$H = \rho C_h u_L (C_p T_L + gz - C_p T_{sk})$$

$$C_h = f(Ri_B, z_{oh}, z_{om})$$

z_{oh}, z_{om} Roughness length for heat and momentum

Dependent on surface/vegetation type

Vegetation role: some recaps

- **Energy balance equation**

$$(1-a)R_S^{\downarrow} + \varepsilon_g R_T^{\downarrow} - \varepsilon_g \sigma T_{sk}^4 + H + \lambda E = G$$

➔ Latent heat (LE) is related to vegetation through:

Evapotranspiration and momentum exchange

$$E = \frac{\rho_a}{r_c + r_a}\left[q_a - q_{sat}(T_{sk})\right]$$

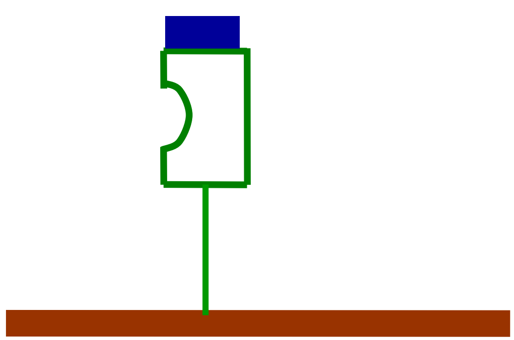
$$r_c = \frac{r_{s,\min}}{LAI} f_1\left(R_S^{\downarrow}\right) f_3\left(\overline{\theta}\right) f_4\left(D_a\right)$$

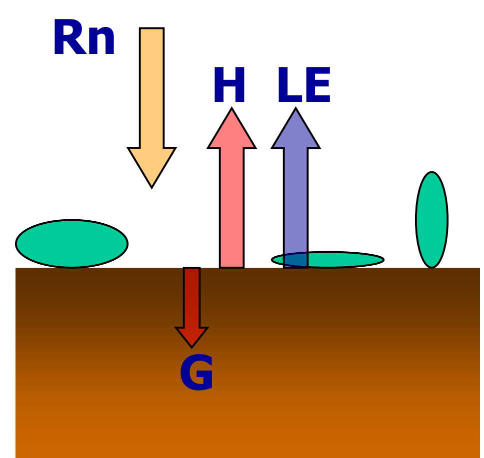
$$r_a = \frac{1}{C_h u_L}, C_h = f(Ri_B, z_{oh}, z_{om})$$

Interception evaporation=

f(Interception reservoir)➔f(LAI))

Wet vegetation



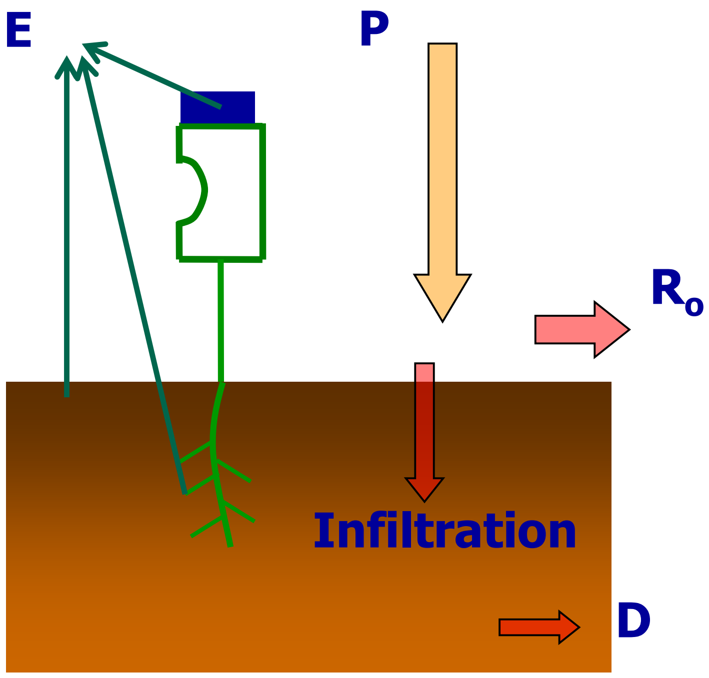


Vegetation role: some recaps

- **Water balance equation**

$$\partial W/\partial t = P - E - Ro - I - D$$

$\partial W/\partial t$ = change in water storage
P= precipitation
E= evapotranspiration
Ro= runoff
I =Infiltration
D=lateral diffusion



Evaporation from:

Bare soil

Interception layer

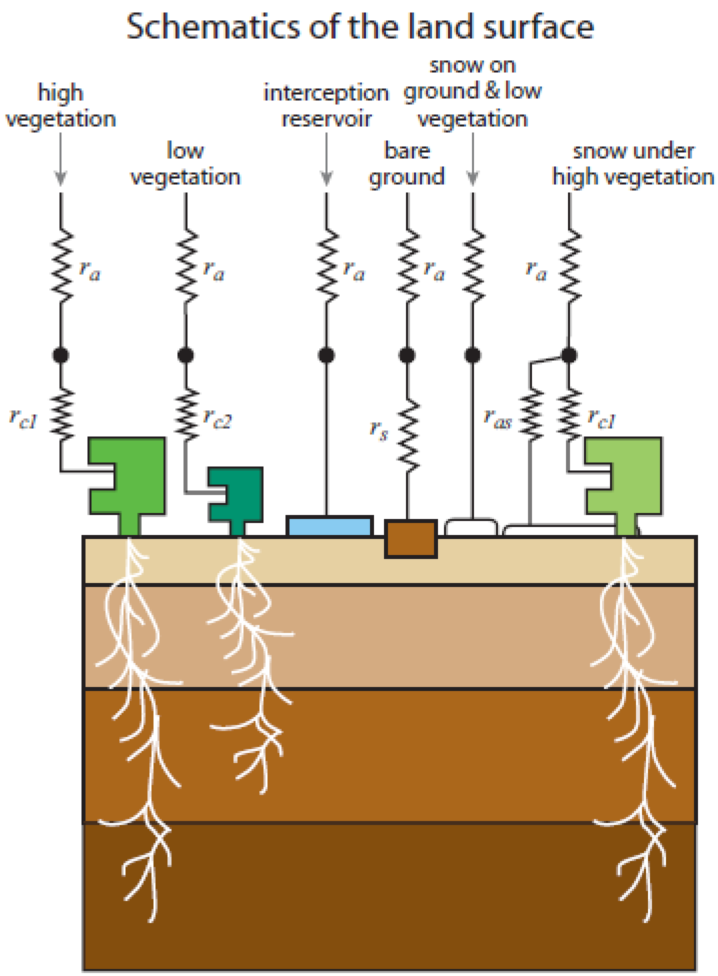
Root transpiration

Infiltration also depend on through fall amount

Vegetation heterogeneity

- Land surface is heterogeneous blend of vegetation at many scales
  - forest/cropland/urban area
  - within forest: different trees/moss/understories
- Most LSMs use set of parallel “plant functional types” (PFTs) with specific properties
  - gridbox mean or tiled
  - Some ecological models treat species competition and dynamics within PFTs
- Properties of PFTs
  - LAI
  - rooting depth
  - roughness
  - albedo
  - emission/absorption of organic compounds

CHTESSEL :a tiles approach



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Land/vegetation	Sea and ice
High vegetation	Open sea / unfrozen lakes
Low vegetation	Sea ice / frozen lakes
High vegetation with snow	
Snow on low vegetation	
Bare ground	
Interception layer	

CHTESSEL geographic characteristics

Fields	ERA15	TESSEL	CHTESSEL
Vegetation	Fraction	Fraction of low Fraction of high	Fraction of low Fraction of high
Vegetation type	Global constant (grass)	Dominant low type Dominant high type	Dominant low type Dominant high type
Albedo	Annual	**Monthly**	Monthly
LAI r_{smin}	Global constants	**Annual, Dependent on vegetation type**	**Monthly**
Root depth Root profile	1 m Global constant	**Annual, Dependent on vegetation type**	Annual, Dependent on vegetation type

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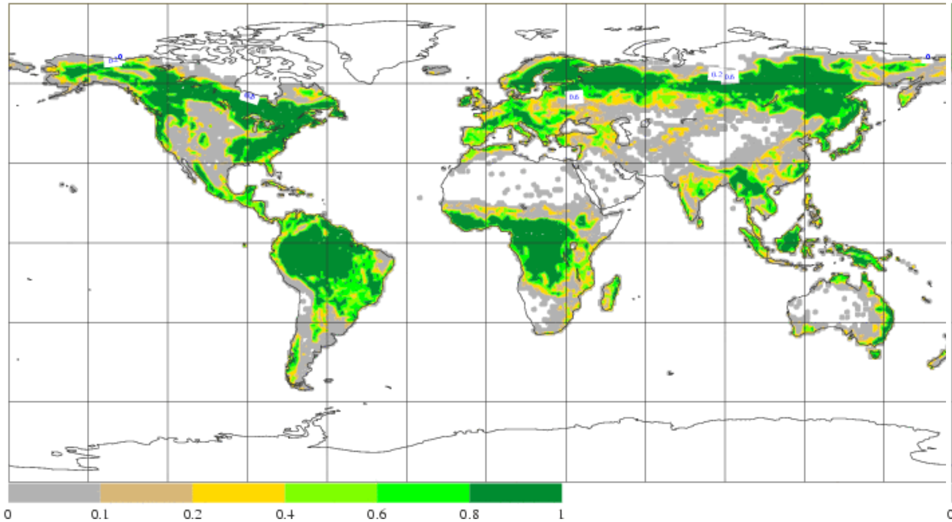
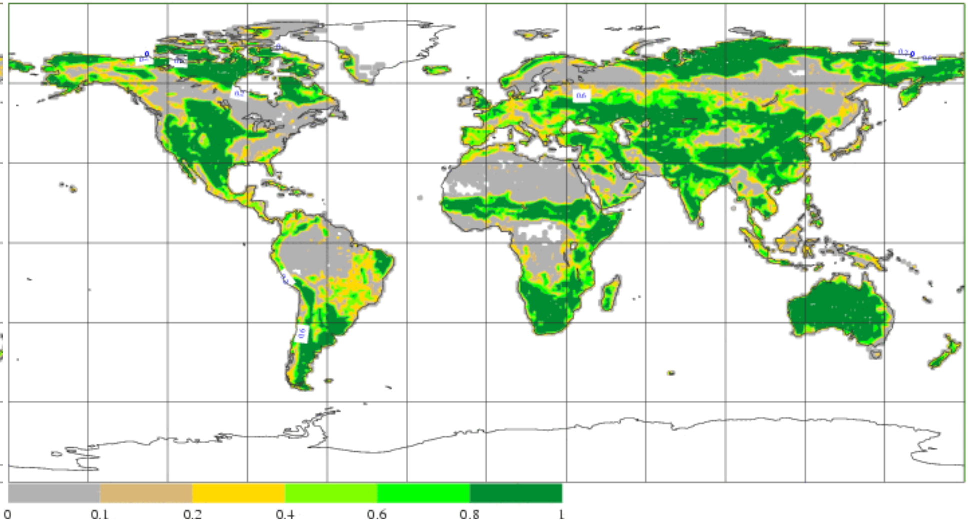
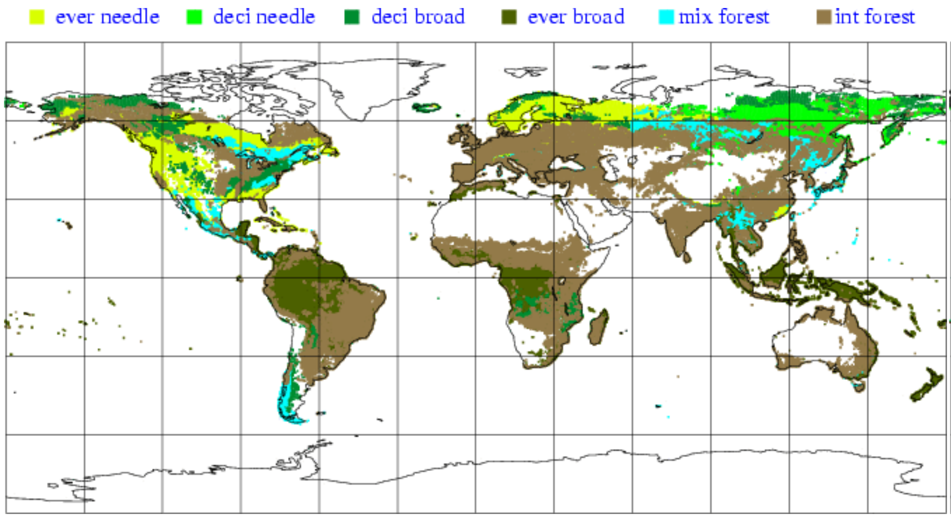
High vegetation fraction



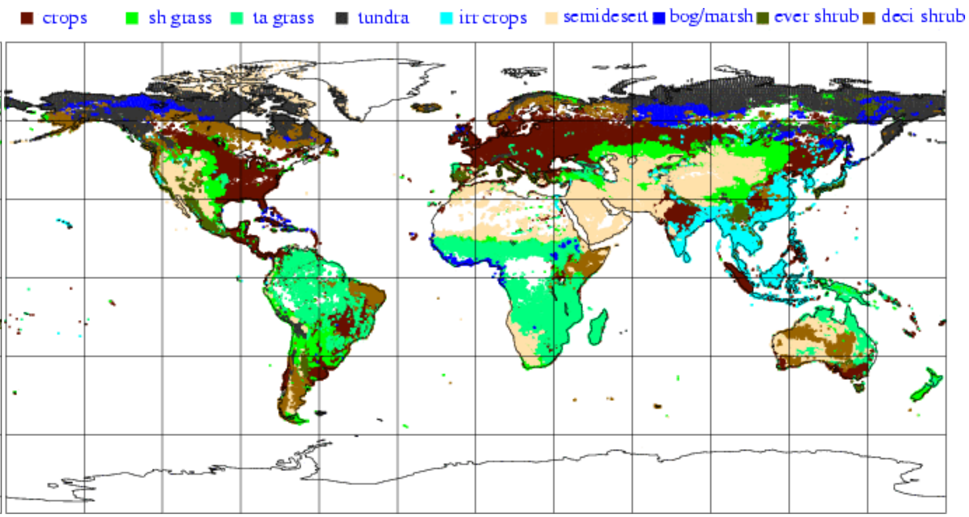
Low vegetation fraction



High vegetation Types



Low vegetation Types



Aggregated from GLCC 1km

Vegetation types dependent parameters

Index	Vegetation type	H/L	$r_{s,min}$ (sm^{-1})	LAI (m^2m^{-2})	c_{veg}	g_D (hPa^{-1})	a_r	b_r
1	Crops, mixed farming	L	180	3	0.90	0	5.558	2.614
2	Short grass	L	110	2	0.85	0	10.739	2.608
3	Evergreen needleleaf trees	H	500	5	0.90	0.03	6.706	2.175
4	Deciduous needleleaf trees	H	500	5	0.90	0.03	7.066	1.953
5	Deciduous broadleaf trees	H	175	5	0.90	0.03	5.990	1.955
6	Evergreen broadleaf trees	H	240	6	0.99	0.03	7.344	1.303
7	Tall grass	L	100	2	0.70	0	8.235	1.627
8	Desert	–	250					
9	Tundra	L	80					
10	Irrigated crops	L	180					
11	Semidesert	L	150					
12	Ice caps and glaciers	–	–					
13	Bogs and marshes	L	240					
14	Inland water	–	–					
15	Ocean	–	–					
16	Evergreen shrubs	L	225					
17	Deciduous shrubs	L	225					
18	Mixed forest/woodland	H	250					
19	Interrupted forest	H	175					
20	Water and land mixtures	L	150					

Era Interim cycle

Current 41r1 cycle

Index	Vegetation type	H/L	$r_{s,min}$ (sm^{-1})	c_{veg}	g_D (hPa^{-1})	a_r	b_r
1	Crops, mixed farming	L	100	0.90	0	5.558	2.614
2	Short grass	L	100	0.85	0	10.739	2.608
3	Evergreen needleleaf trees	H	250	0.90	0.03	6.706	2.175
4	Deciduous needleleaf trees	H	250	0.90	0.03	7.066	1.953
5	Deciduous broadleaf trees	H	175	0.90	0.03	5.990	1.955
6	Evergreen broadleaf trees	H	240	0.99	0.03	7.344	1.303
7	Tall grass	L	100	0.70	0	8.235	1.627
8	Desert	–	250	0	0	4.372	0.978
9	Tundra	L	80	0.50	0	8.992	8.992
10	Irrigated crops	L	180	0.90	0	5.558	2.614
11	Semidesert	L	150	0.10	0	4.372	0.978
12	Ice caps and glaciers	–	–	–	–	–	–
13	Bogs and marshes	L	240	0.60	0	7.344	1.303
14	Inland water	–	–	–	–	–	–
15	Ocean	–	–	–	–	–	–
16	Evergreen shrubs	L	225	0.50	0	6.326	1.567
17	Deciduous shrubs	L	225	0.50	0	6.326	1.567
18	Mixed forest/woodland	H	250	0.90	0.03	4.453	1.631
19	Interrupted forest	H	175	0.90	0.03	4.453	1.631
20	Water and land mixtures	L	150	0.60	0	–	–

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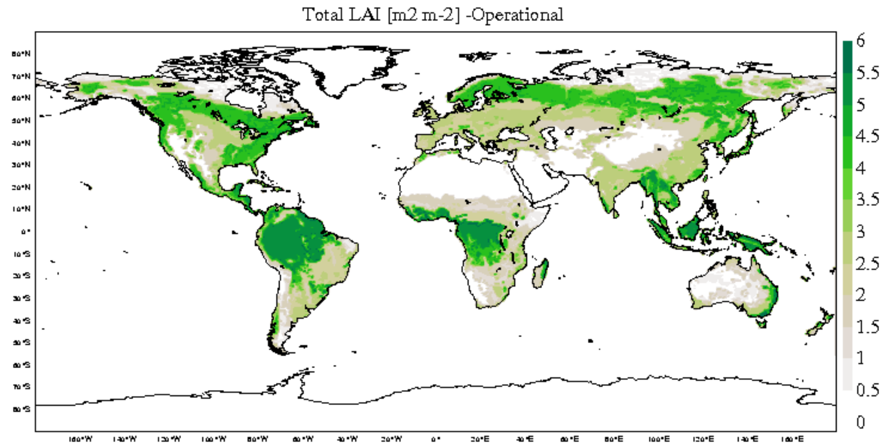
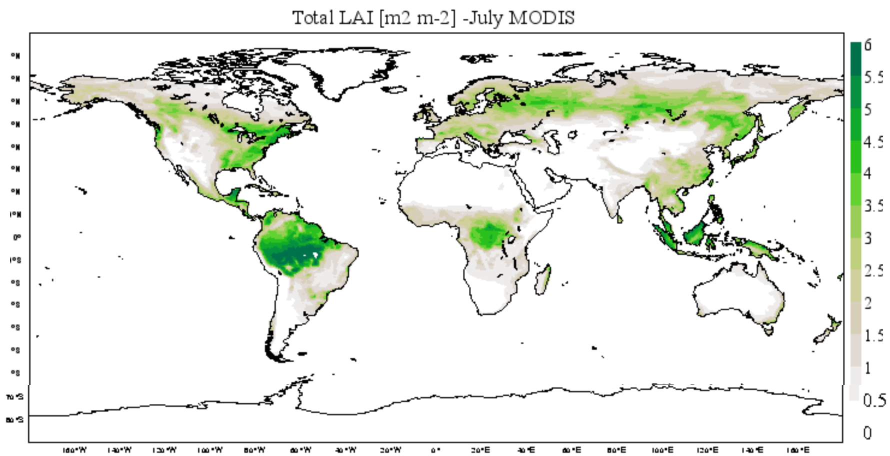
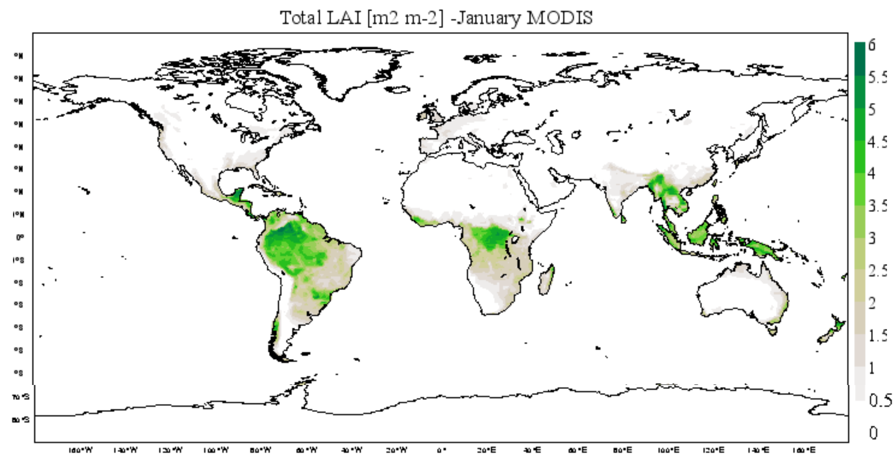
More realistic vegetation dynamic: Seasonal varying Leaf Area Index

Seasonal Varying Leaf Area Index







Obtained by the inversion of a 3D radiative transfer model which compute the LAI and FPAR based on the biome type and an atmospherically corrected surface reflectance thanks to a look-up-table

➔derived 8years (2000-2008) climatological time serie

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Expected LAI impact on screen level Temperature

For vegetated area the evapotranspiration is parameterized as:

$$E_i = \frac{\rho_\mathrm{a}}{r_\mathrm{a} + r_\mathrm{c}} [q_\mathrm{L} - q_\mathrm{sat}(T_{\mathrm{sk},i})]$$

Where the canopy resistance r_c is defined following Jarvis(1976) as:

$$r_\mathrm{c} = \frac{r_\mathrm{S,min}}{LAI} f_1(R_\mathrm{s}) f_2(\bar{\theta}) f_3(D_\mathrm{a})$$

Where $r_{s,min}$ is the minimum stomatal resistance, ***LAI*** is the leaf area index and $f1$, $f2$, $f3$ are respectively function of the downward shortwave radiation R_s, soil moisture θ and vapour deficit D_a

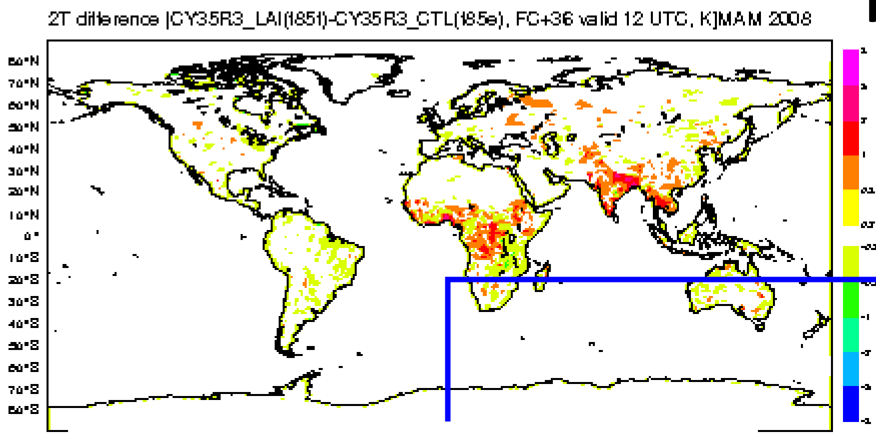
If *LAI* ↘ then r_c ↗ and *E* ↘ so *T2m* ↗

If *LAI* ↗ then r_c ↘ and *E* ↗ so *T2m* ↘

Analysis experiment: fc experiment validation

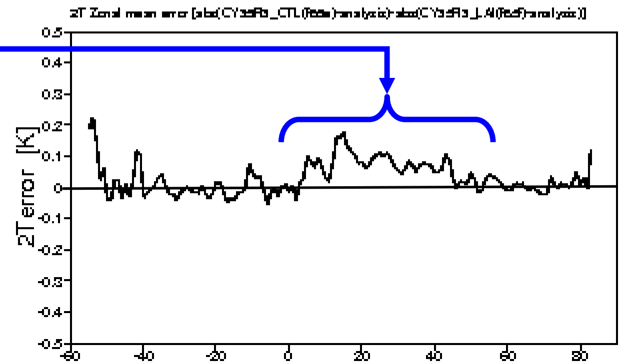
Sensitivity

T 2m



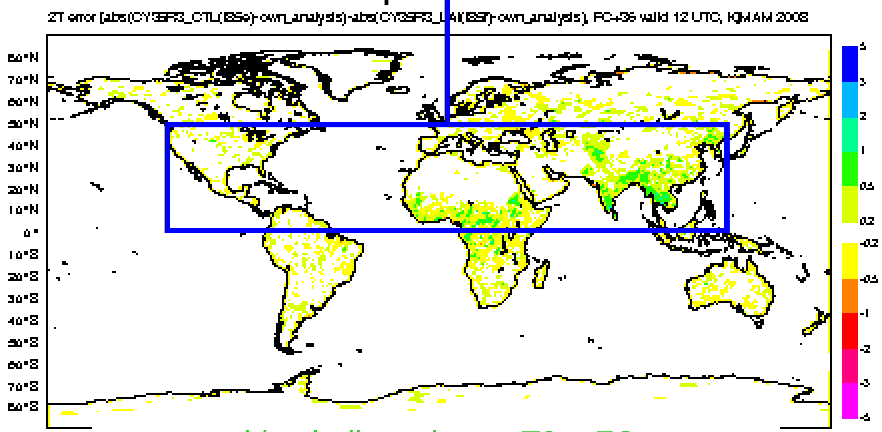
green-to-blue indicateT2m FC cooling

Setup:	T255
	14/02/2008 -1/09/2008
	Seasonal LAI vs fixed LAI

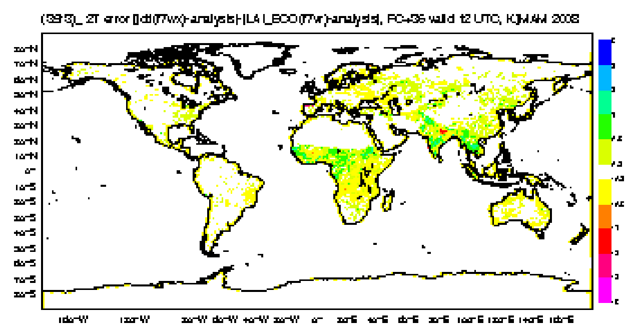


Zonal mean impact

Impact



green-to-blue indicate better T2m FC



Fc impact

The MODIS LAI introduces a consistent warming seen in FC36h (12UTC) due to reduction of LAI in spring, (increasing vegetation resistance to ET).

This has beneficial impact on near surface temperature forecast (green being positive impact in reducing t2m bias by ~0.5degree)

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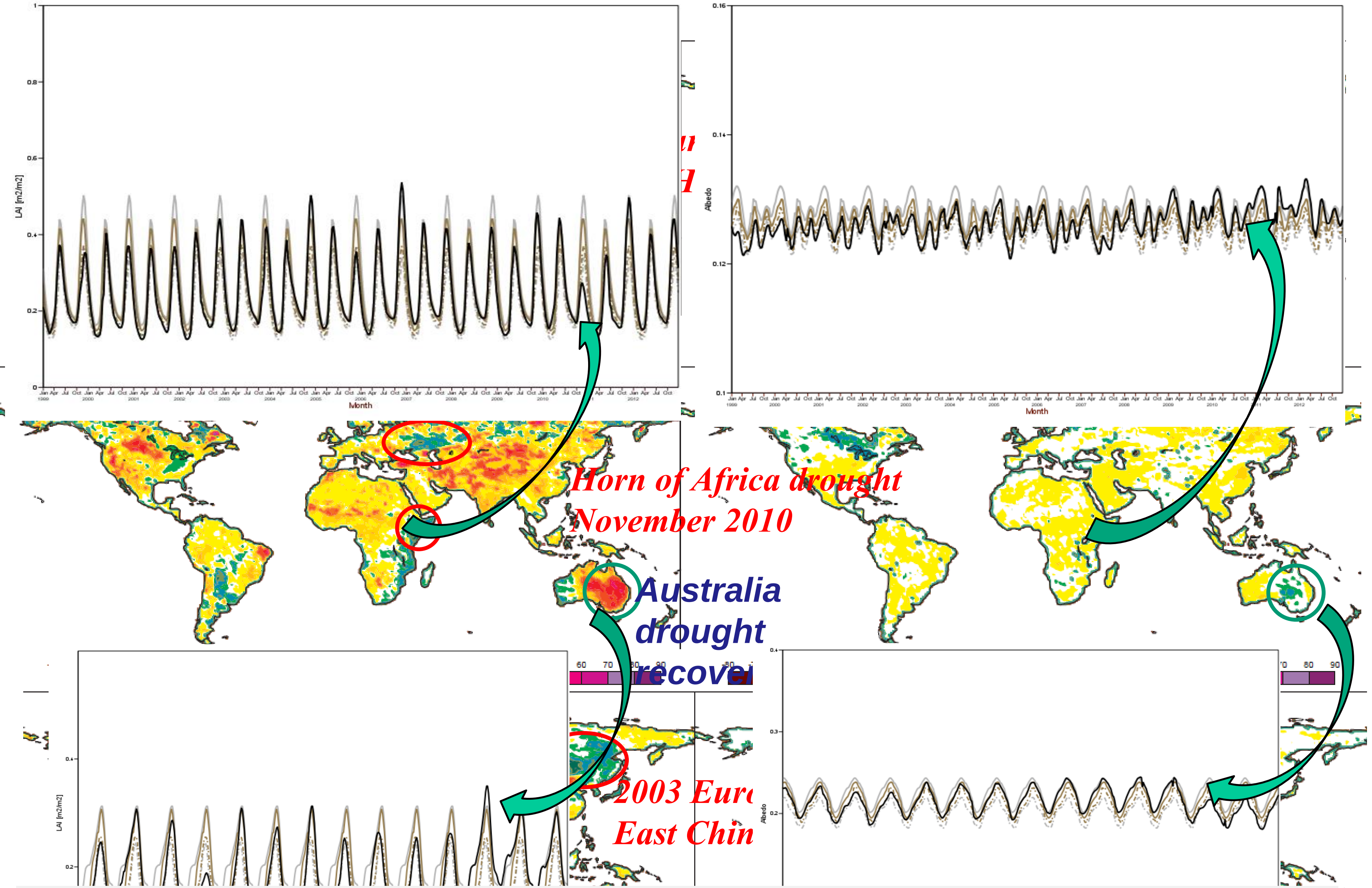
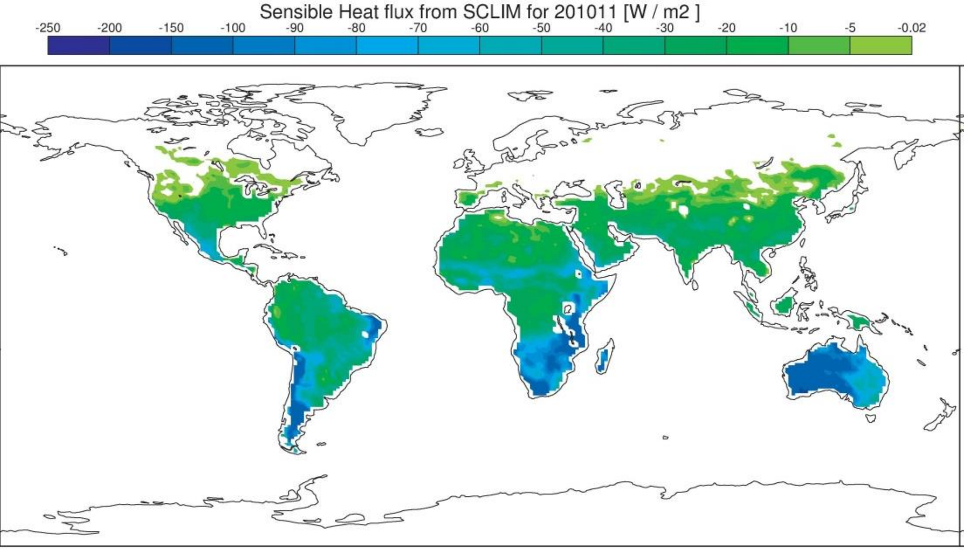
More and more realistic vegetation dynamic: Assimilation of Near Real Time LAI/Albedo

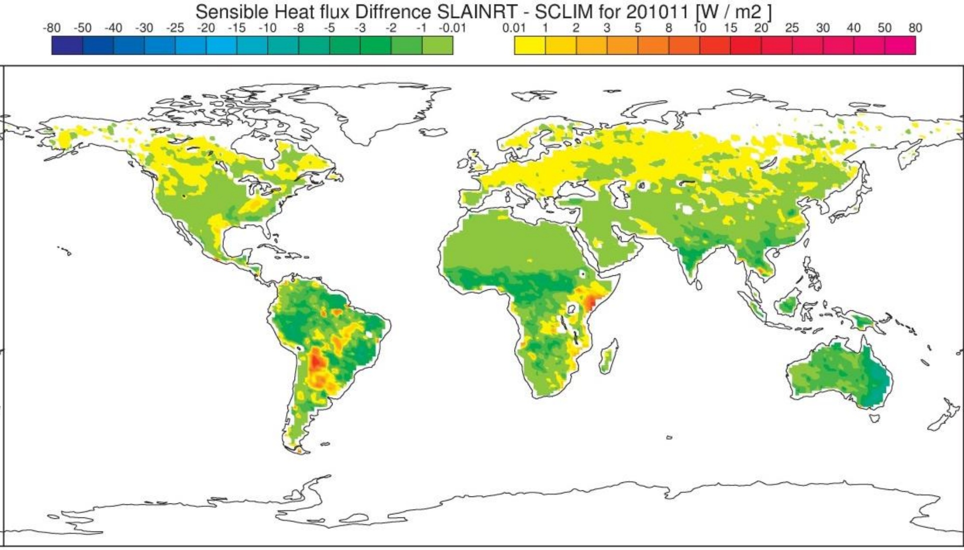


- ➔ NRT analysed LAI is able to fairly detect/monitor anomalous year
- ➔ The analysed LAI and albedo signal can be covariant mainly during wet year.

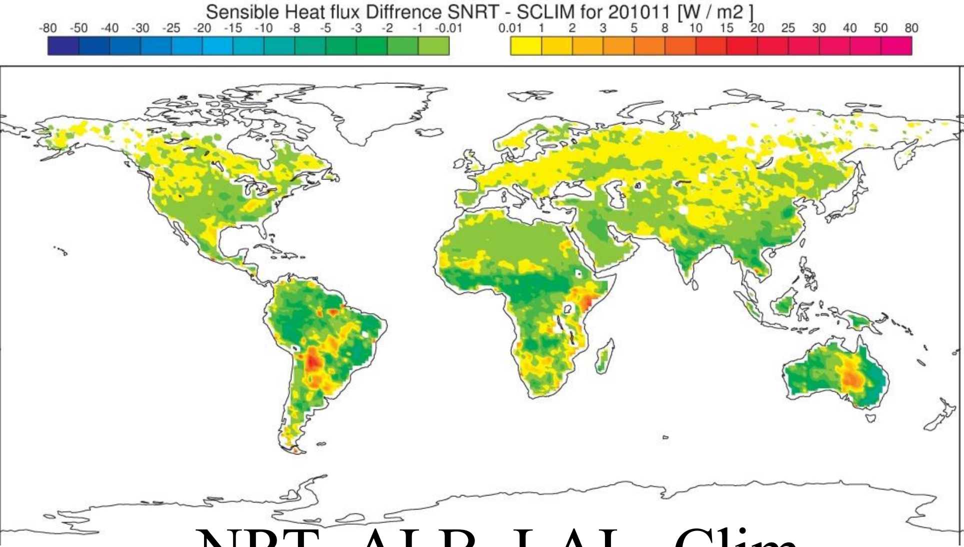
Sensible Heat flux



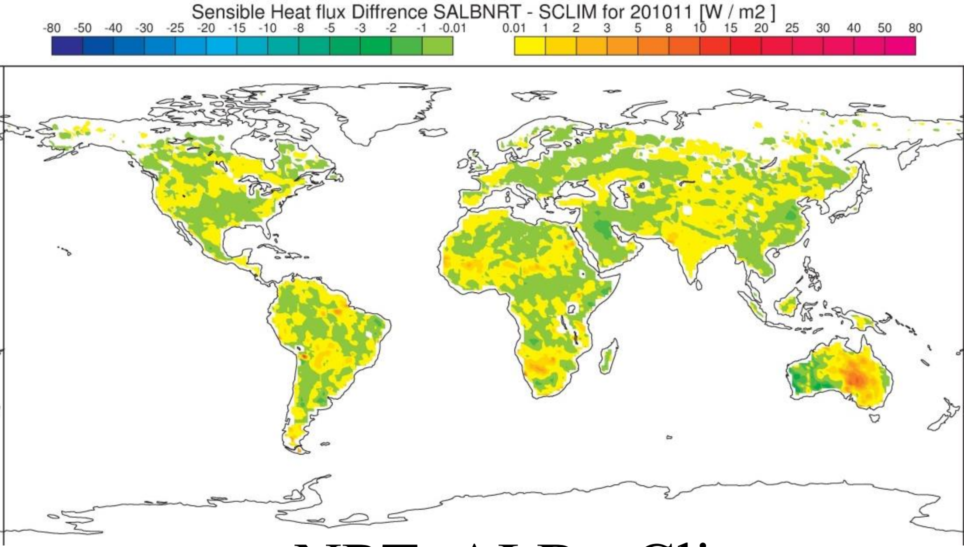
Clim



NRT_LAI - Clim

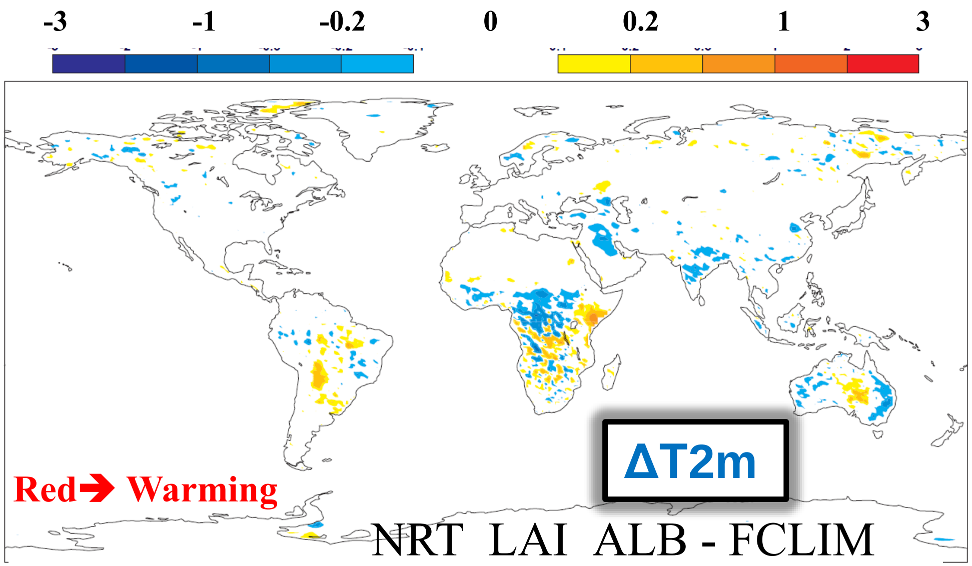


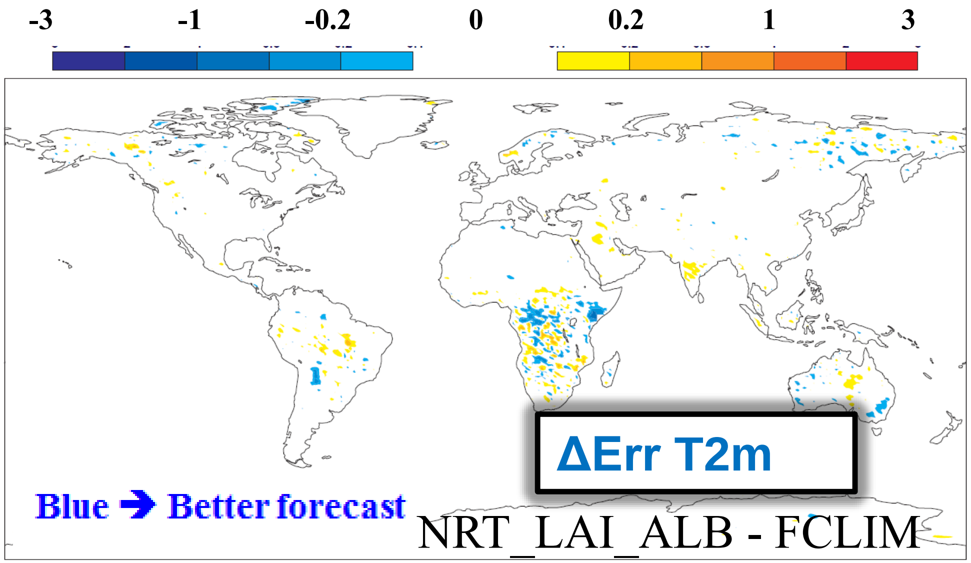
NRT_ALB_LAI - Clim



NRT_ALB - Clim

2m temperature sensitivity in coupled run





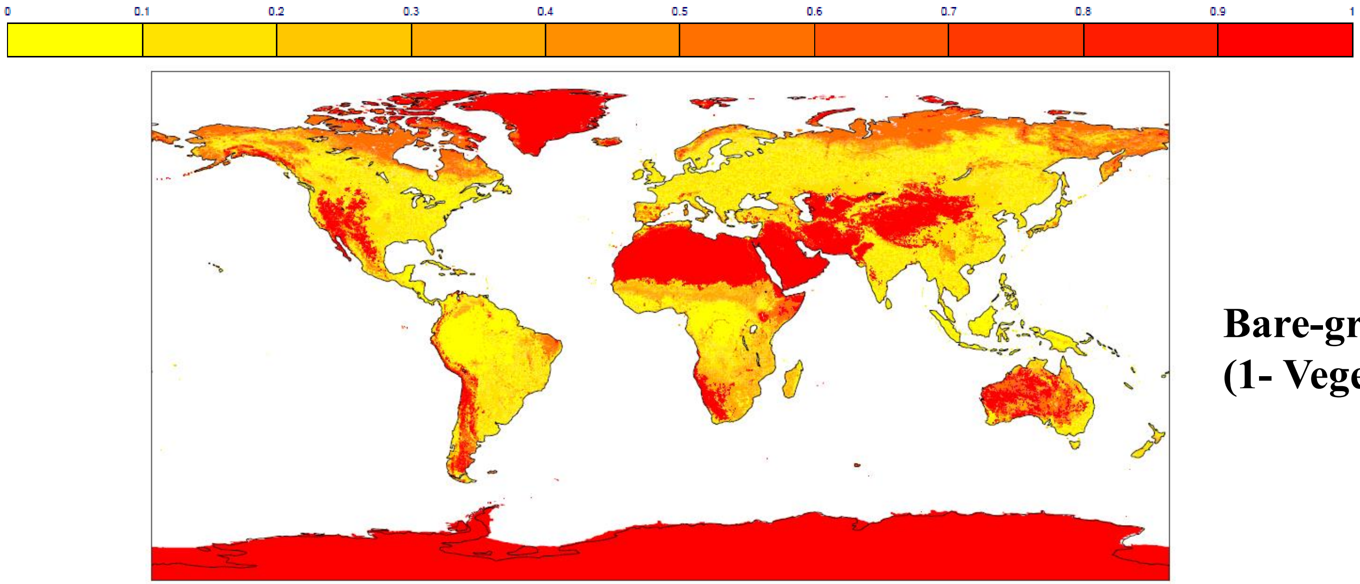
Even more realistic vegetation dynamic: Variable vegetation cover

Februar
y

May

July

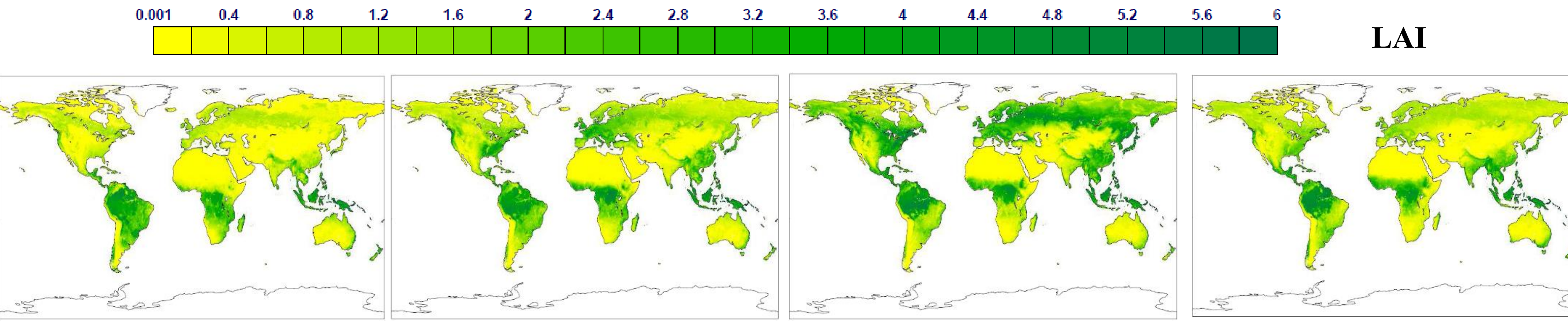
October

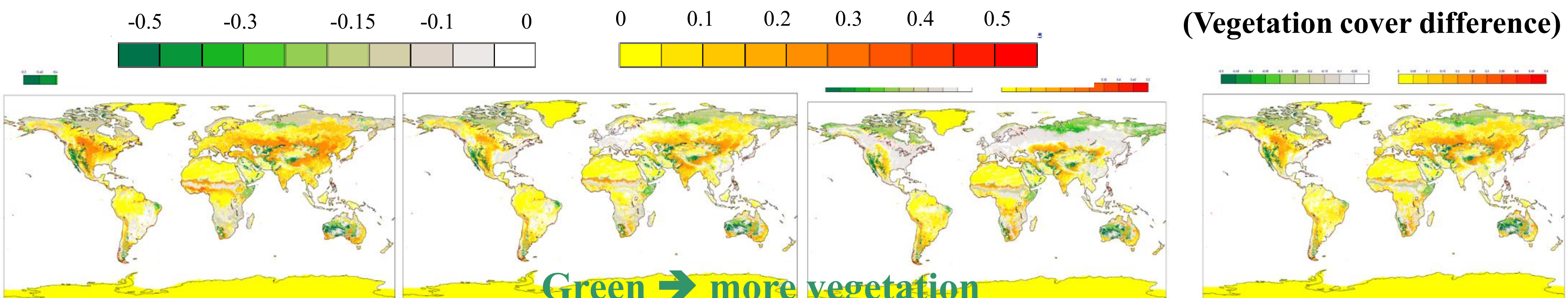


Bare-ground/snow cover (1- Vegetation fraction)

➔ vegetation cover variation based on satellite observation of Leaf Area Index according to a modified Beer-Lamber law with clumping

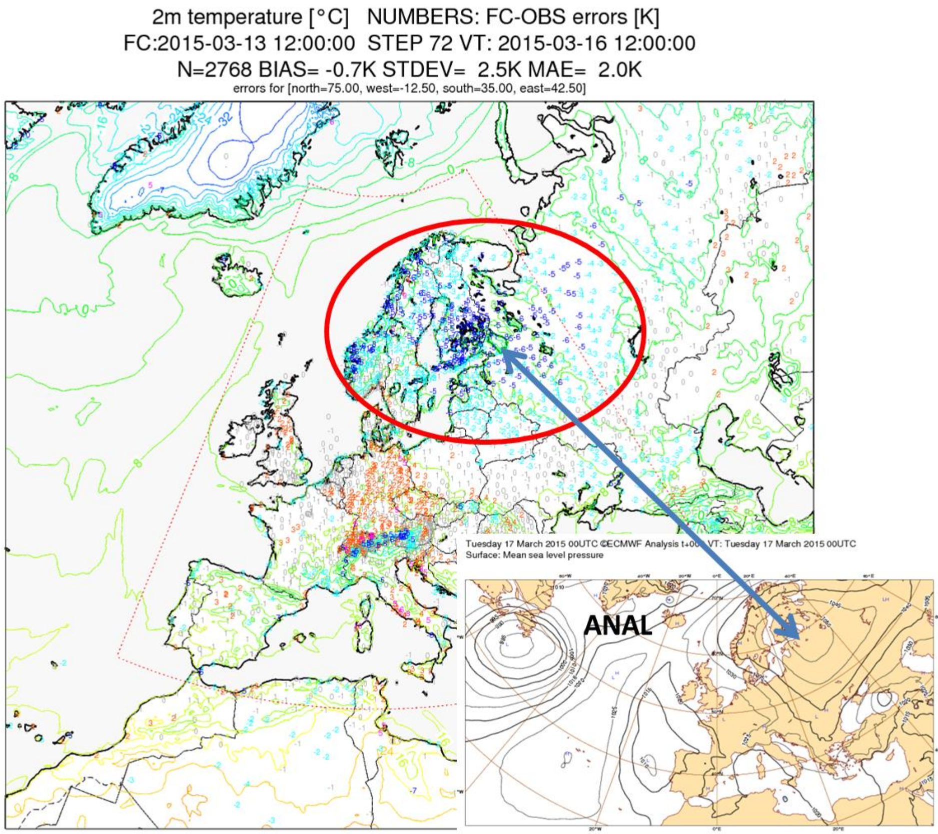
$$C_{veg} = 1 - e^{0.5\omega LAI}$$

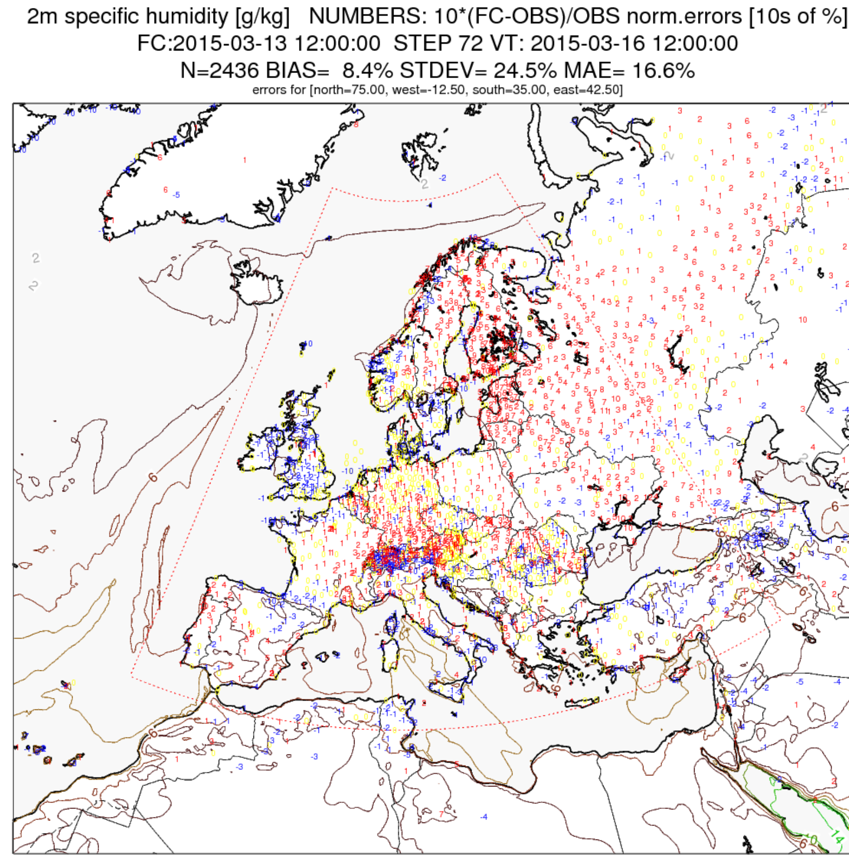




➔ Physically-based seasonal variability of the vegetation cover

Impact in weather forecast mode





Cold bias on 2m Temperature 4K on average

Moist bias on 2m specific humidity 1g/kg on average

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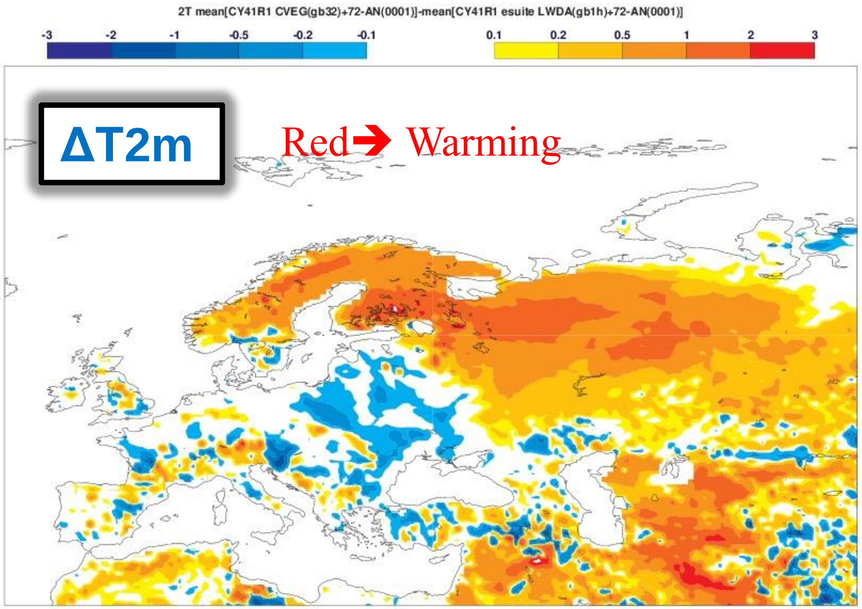
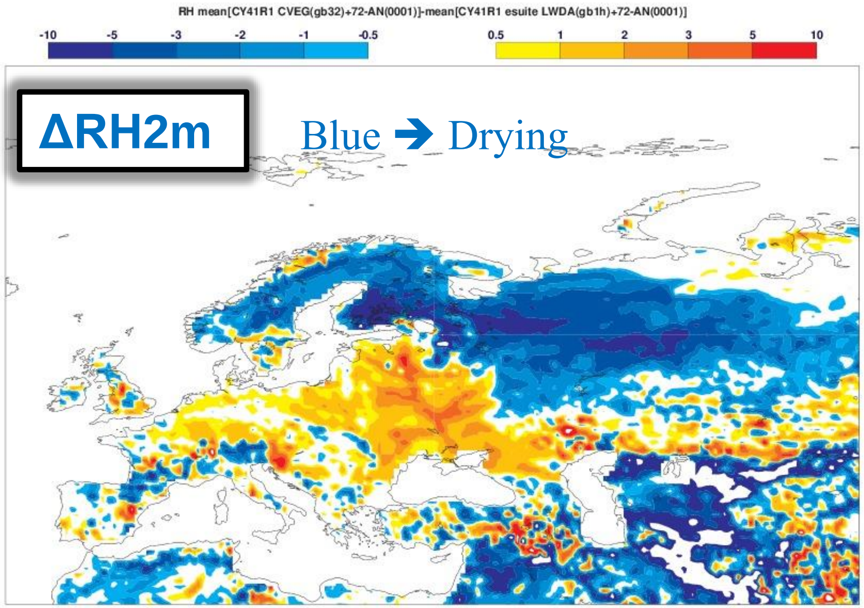
Weather forecasts sensitivity

➔Check the T 2m and RH on short term forecast fc+72 valid 12 UTC, March 2015



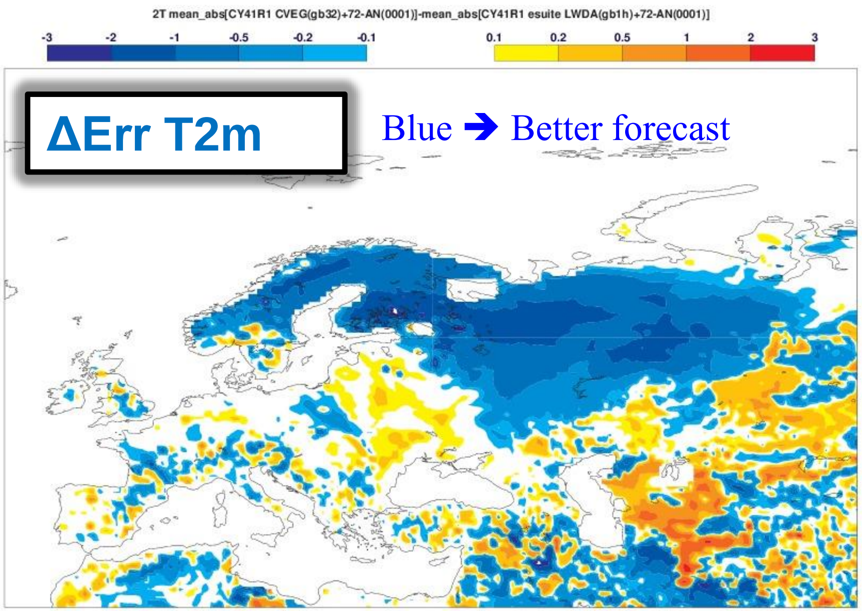


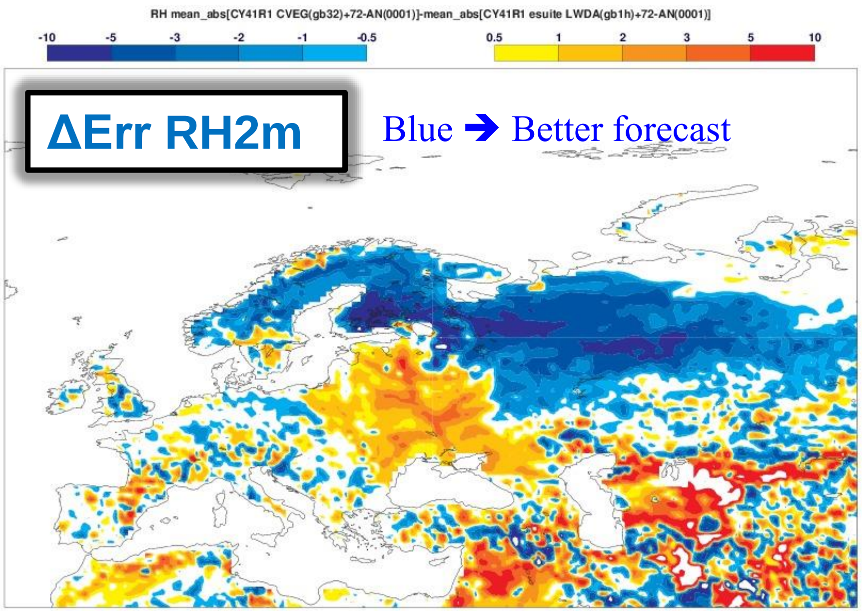
Sensitivity = CVEG - CTL ,

if >0 => Warming / adding moisture

if <0 => Cooling / removing moisture

Weather forecasts impact



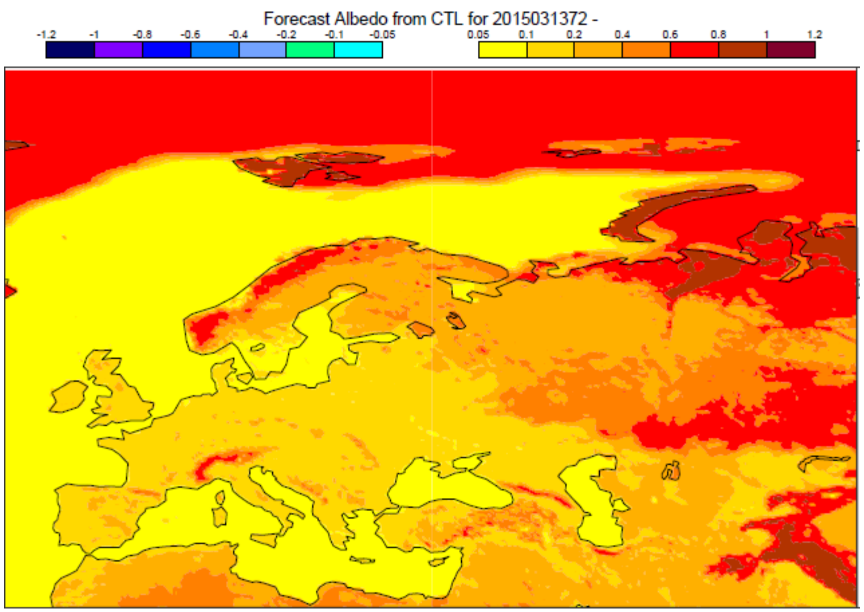


$$Impact = |CTL - analysis| - |CVEG - analysis| ,$$

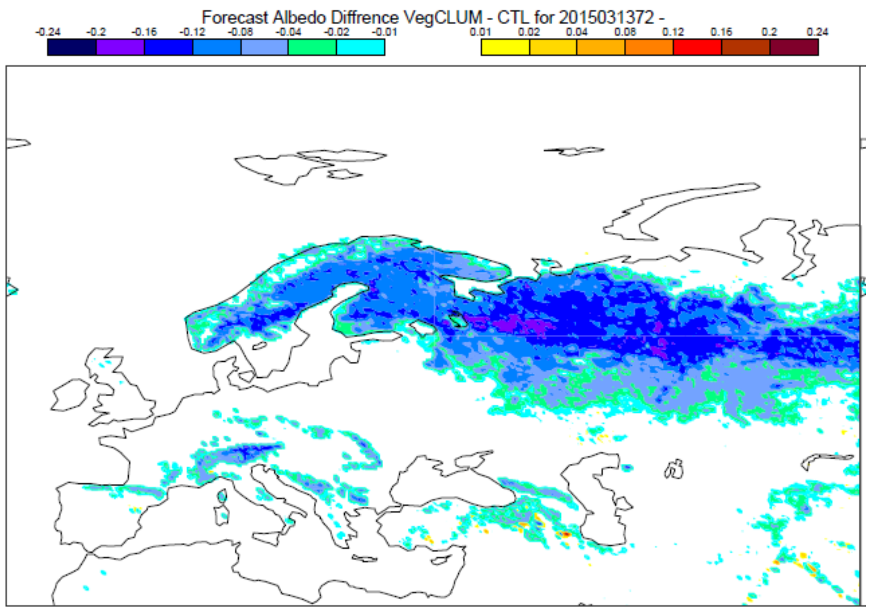
if >0 => relative error reduction from the analysis (positive impact)

if <0 => relative error increase from the analysis (negative impact)

Behind the scene



Forecast Albedo for CTL

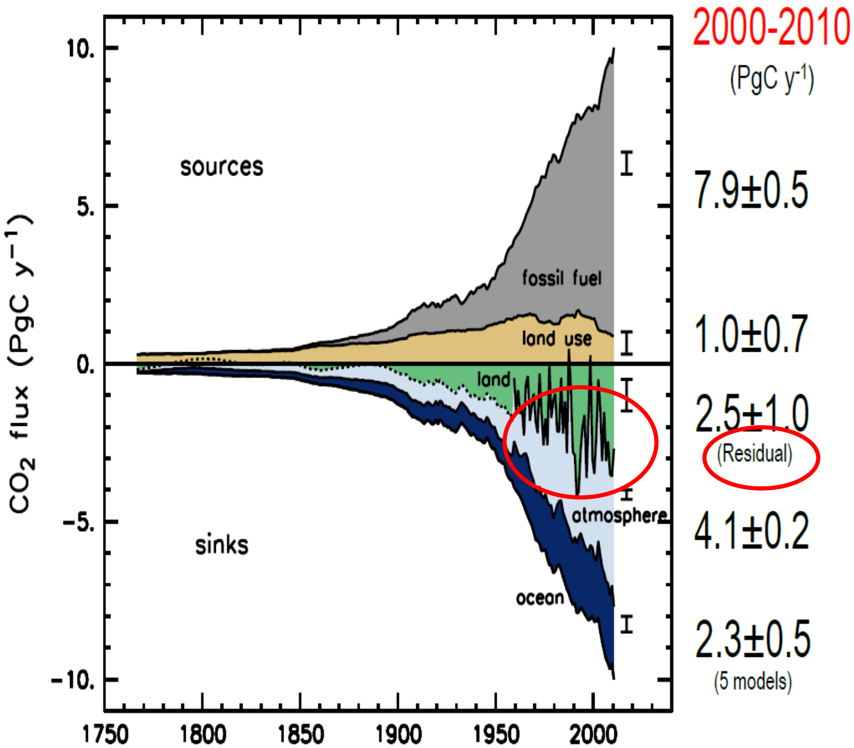


CVEG albedo – CTL albedo

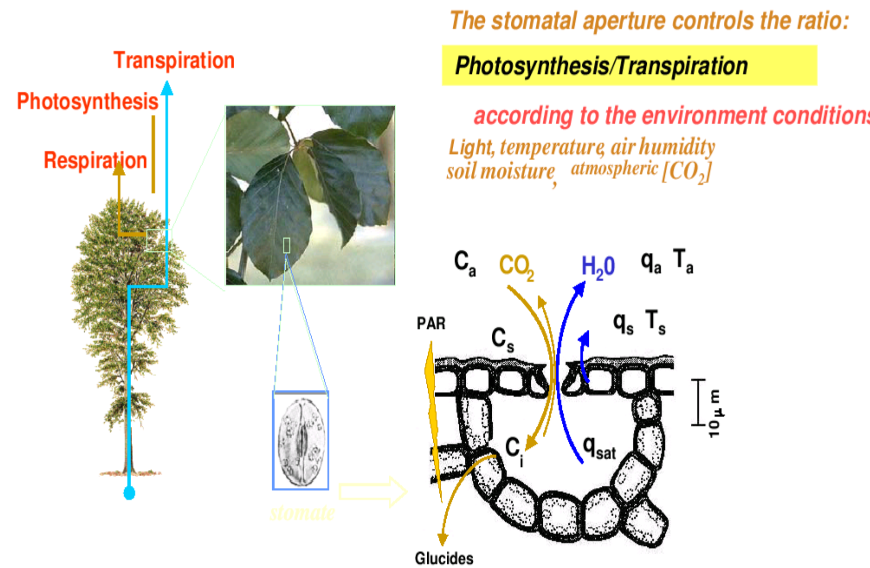
➔ Change in the vegetation cover is linked with a change in the forest albedo in presence of snow (in this case)

Introducing Land Carbon parametrisation

Why increasing complexity?



Global Carbon Project 2011; Updated from Le Quéré et al. 2009, Nature G; Canadell et al. 2007, PNAS



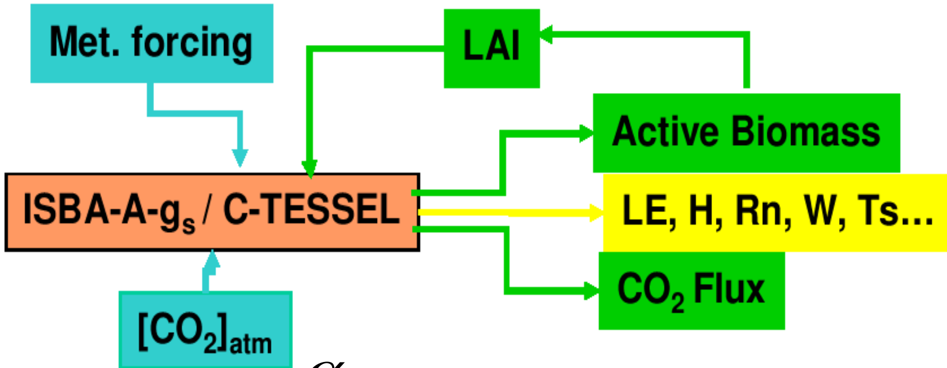
CO2 and water vapour share the same pathway

The land surface natural contribution to the global carbon budget is still highly uncertain

➔ A better representation of the vegetation processes

➔ And also attempt to reduce uncertainties from the global carbon budget

Land carbon/photosynthesis-based canopy resistance parameterisation



$$A_n = \frac{\alpha}{r_{cc}}(C_s - C_i)$$

$$E = \frac{\beta}{r_c + r_a}(q_a - q_{sat}), r_c = f(r_{cc})$$

- $A_n = \rho f(\text{soil m}) \Delta CO_2 / r_c$

➔ r_c back-calculated from
- Empirical soil moisture dependence
- CO_2-gradient ΔCO_2 is also f($q_{sat} - q$)
- Net photosynthetic rate A_n
  - $A_{n,max}$
  - Photosynthetic active Radiation (PAR)
  - temperature
  - $[CO_2]$

CTESSEL combines HTESSEL (Balsamo et al. 2009) with the A-gs model used within the ISBA-Ags (Calvet et al.1998) and developed by Jacobs et al. (1996);

➔Account for the effect of CO2 concentration and the interactions between all environment factors on the stomatal aperture.

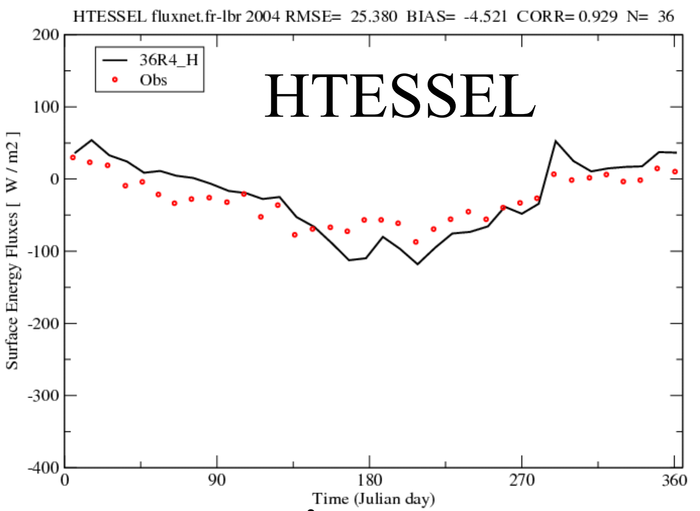
➔Replaces the Jarvis-type stomata conductance by a photosynthesis dependant-type stomata conductance (Jacobs et al.1996)

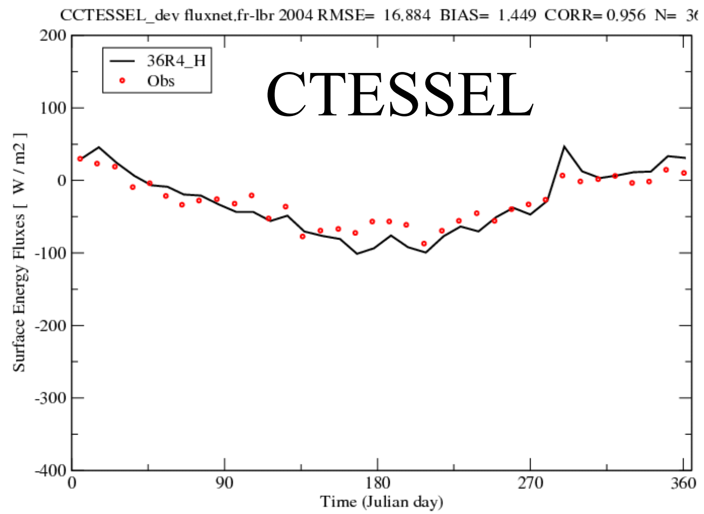
➔The model can account for the vegetation response to the radiation at the surface, temperature, soil moisture stress

➔Vegetation Assimilation of CO2 can be used to drive a vegetation growth module to simulate LAI

➔The Ecosystem Respiration is parameterized as a function of soil temperature, soil moisture and biome type via a reference respiration parameter

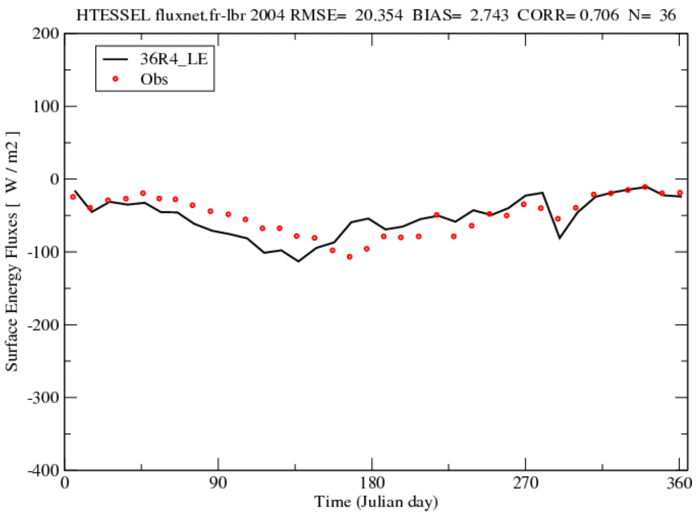
Jarvis Vs photosynthesis-based evapotranspiration (offline run)



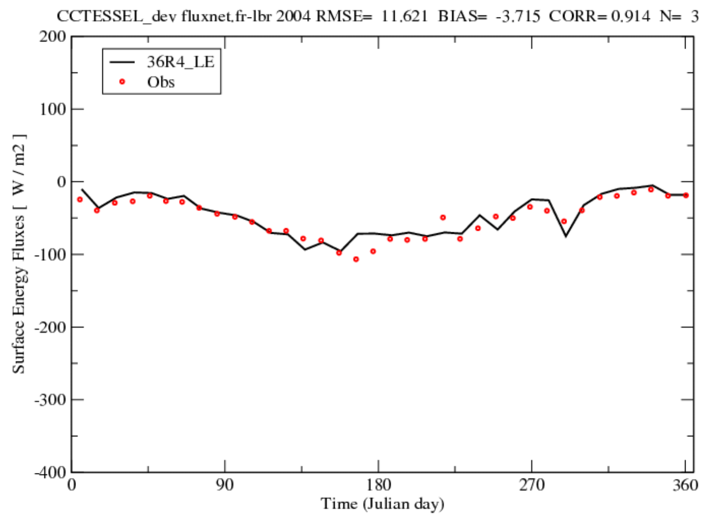


H

Surface sensible heat flux (W/m^2) compared with flux-tower observations over Fr-LBr for HTESSEL (left panel) and CTESSEL (right panel)



LE



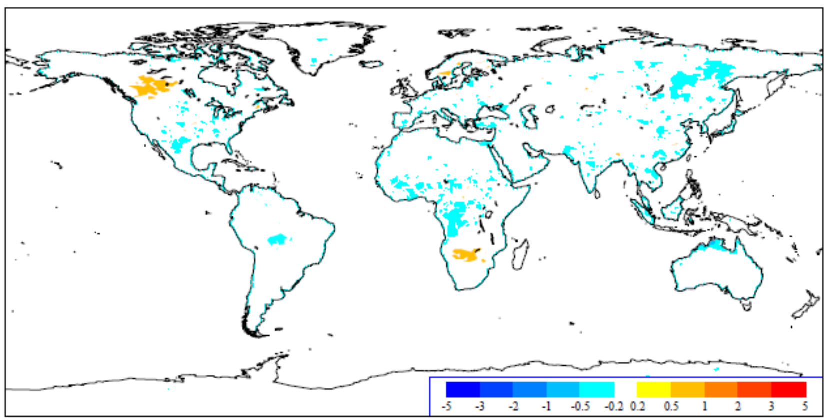
Surface laten heat flux (W/m^2) compared with flux-tower observations over Fr-LBr for HTESSEL (left panel) and CTESSEL (right panel).

- **CTESSEL improves the LE/H simulations (Photosynthesis-based vs Jarvis approach).**

LE/H: When “good” is not enough?
(Interaction with the atmosphere)

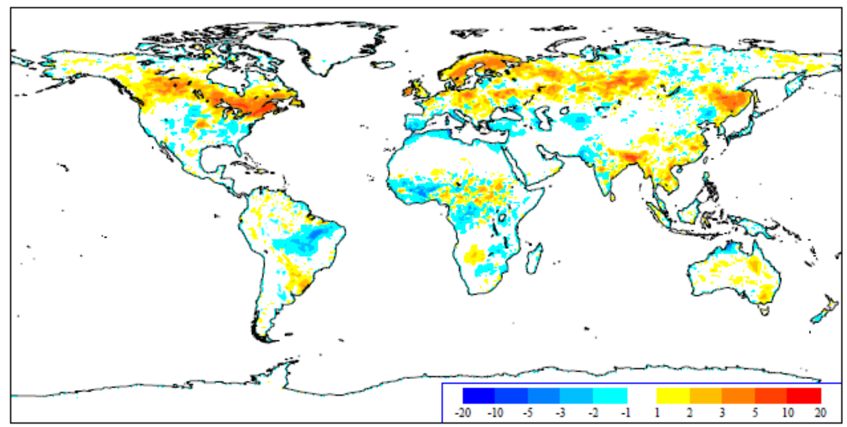
2m T Error differences from the CTL

T925 mean_abs[CY37R1_CTESSEL(ficd)+36-AN(ficd)]-mean_abs[CY37R1(fhrd)+36-AN(fhrd)]



2m Rh Error differences from the CTL

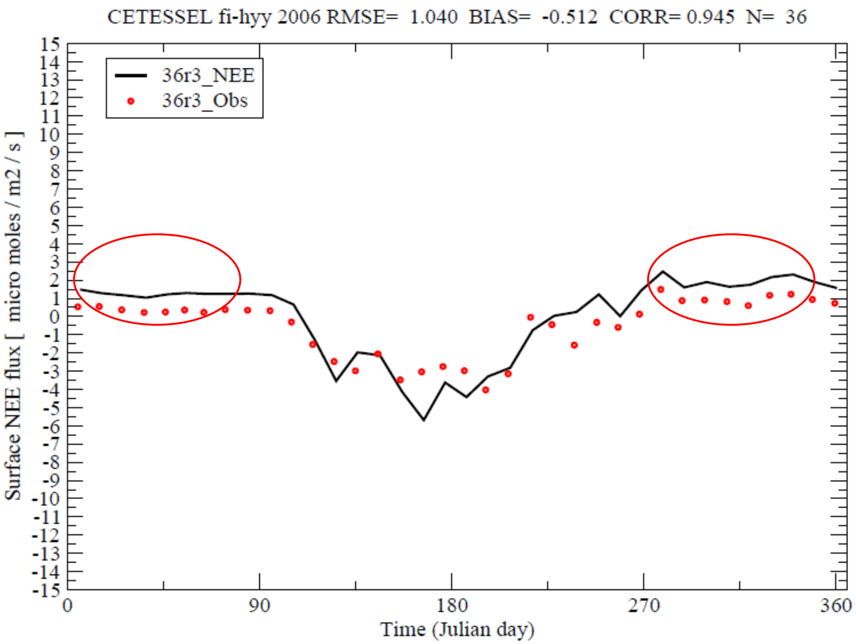
RH mean_abs[CY37R1_CTESSEL(ficd)+36-AN(ficd)]-mean_abs[CY37R1(fhrd)+36-AN(fhrd)]

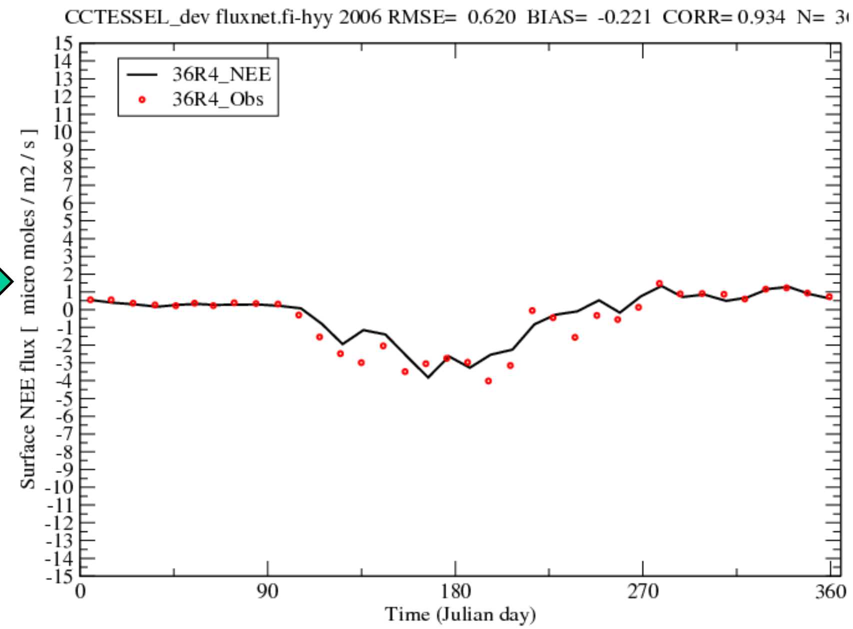


Having better LE/H heat flux from the surface does not always lead to a better atmospheric prediction ➔ interaction with other processes and compensating errors?

Soil Respiration improvement for winter season

$$NEE = A_n - R_{soil}$$





Example of NEE (micro moles /m^2/s) predicted over the site Fi-Hyy taking the cold process into account (right) and previous simulation (left) by CTESSEL (black line) and observed (red dots)

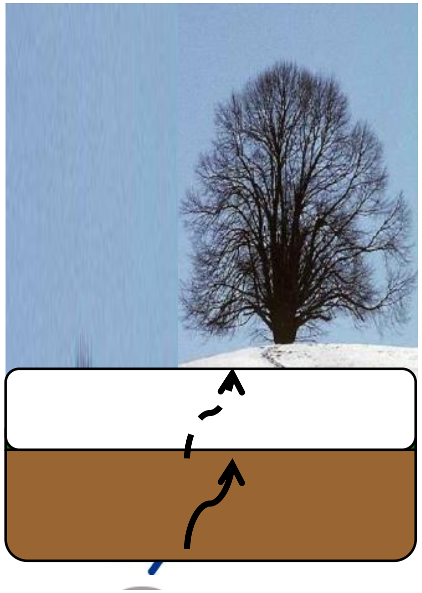
Feedback from the atmosphere can contribute to improve the physical understanding and adjust the contribution from the surface

ECMWF

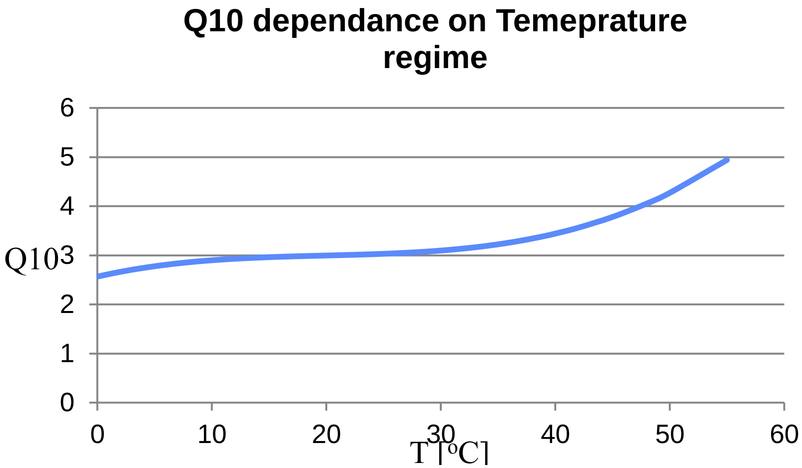
Soil Respiration and winter improvement

$$R_{soil} = R_0 Q_{10}^{(0.1(T_{soil}-25))} f_{sm}$$

$$R_{soil} = R_0 e^{-\alpha . Z_{snow}} Q_{10}^{(0.1(T_{soil}-25))} f_{sm}$$

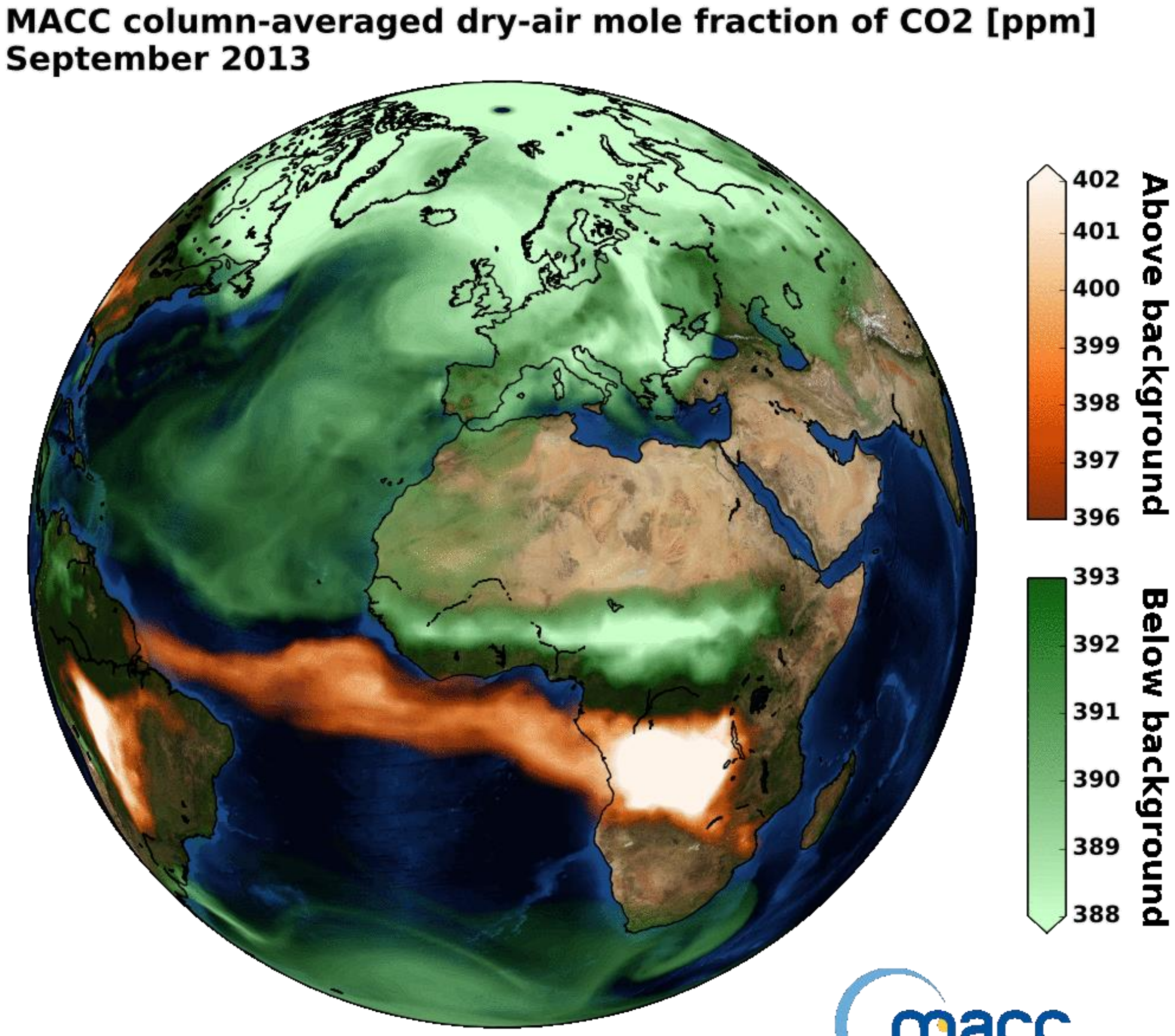


Including a snow attenuation effect on the soil CO2 emission



Including a temeperature dependancy on the Q10 parameter (McGuire et al., 1992)

Near Real Time CO_2 concentration modelled in MACC-II



- CHTESSEL fluxes used in MACC-II (CAMS) to forecast CO2 atmospheric concentrations (16 km global simulation)
- Green colours highlight effects of photosynthetic uptake by vegetation
- Diurnal cycle (fluxes driven) and Synoptic variability (Weather driven) are crucial elements for simulating the CO2 of the Earth system.

Agusti-Panareda et al. (2014, ACP), Boussetta et al. (2013 JGR)

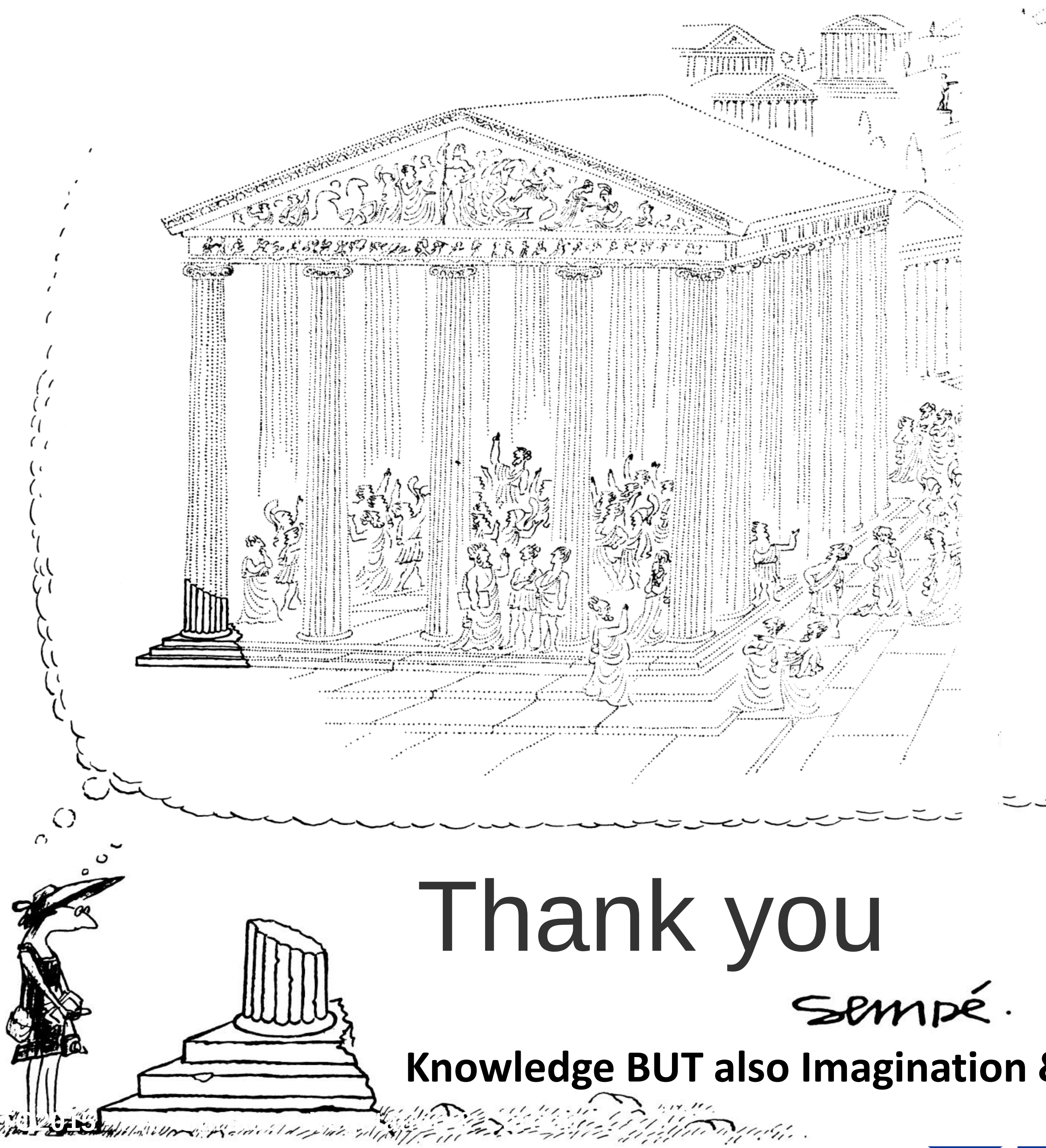
Some thoughts

- Taking into account realistic vegetation dynamics is important for accurate representation of surface fluxes and eventually better atmospheric predictability.

- Carbon, Hydrology and Energy cycles are tightly coupled and an integrated treatment of these processes is a challenge to achieve the necessary accuracy in simulating Net Ecosystem Exchange (CO2 flux) in global models (and as a component of the global carbon budget).

- Enhanced connections between albedo, LAI (and roughness) in Earth System Models (ESMs) will most likely increase the sensitivity to vegetation dynamics, and with increased surface related satellite observation products there is potential for further improvements of NWP systems linked with land surface. (better initialisation/ better process description/ possibility to better tune non-observable model parameters)

- With increased resolution ESMs will have to take into account additional layer of physical complexity such as
    - vegetation interaction with snow/frozen soil,
    - better vegetation dynamics
    - surface- atmosphere coupling and the link with satellite LST,
    - CO2/evapo-transpiration coupled processes and satellite fluorescence observation

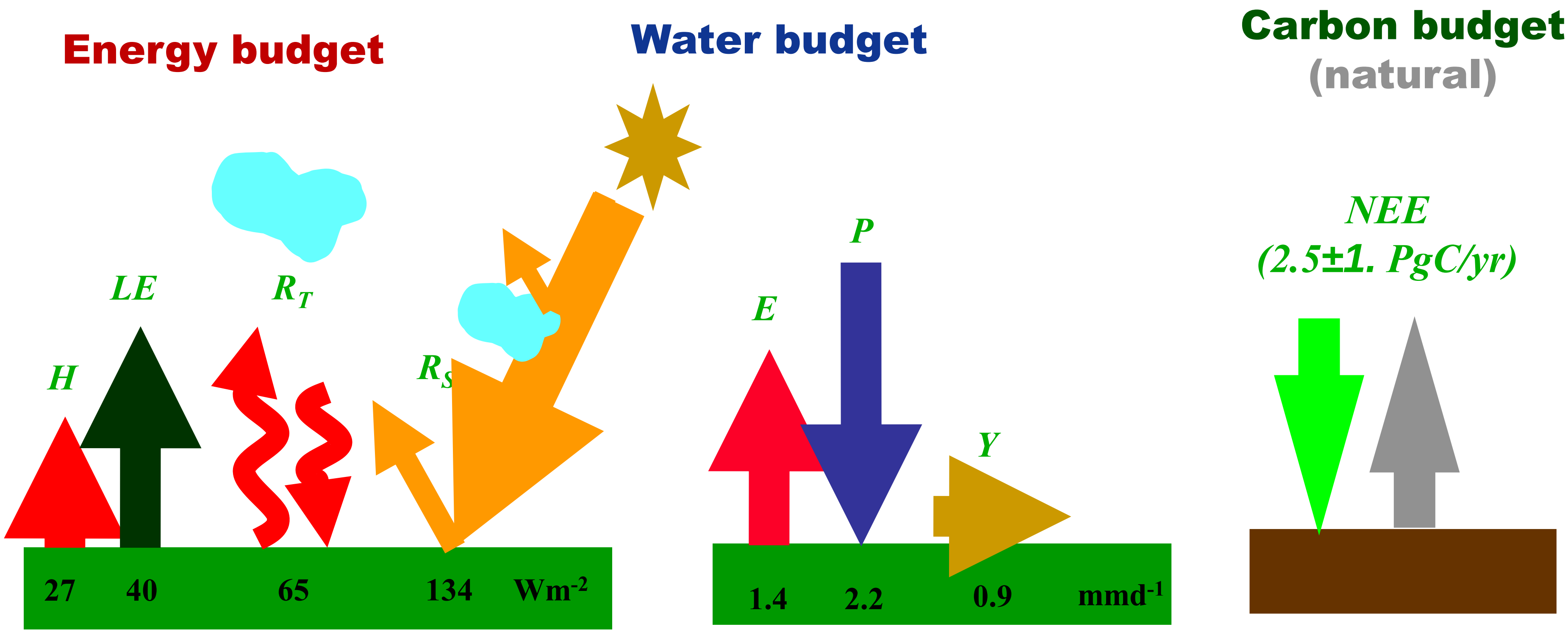


Thank you

Knowledge BUT also Imagination & Creativity

Land surface within GCMs

- Land surface schemes in general circulation models provides boundary conditions for the enthalpy, moisture (and momentum), and recently carbon dioxide equations, and it also enable budget studies



ERA40 land-averaged values 1958-2001

GCP averaged values 2000-2011