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A unique role for HyspIRI in Earth System Science Dynamical Global Vegetation Models

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Presentation outline:

- Background and motivation
- Status of Dynamical Global Vegetation Models
- Uniqueness of HyspIRI data
- **First approach:** Land cover mapping, classification and tables of assigned biophysical variables
- **Second approach:** Retrievals of biophysical variables as direct inputs to models
- **Third approach:** direct assimilation of radiances/reflectances into models
- Perspectives: current trends and way forward

BACKGROUND:

- Developments in the framework of SPECTRA mission within ESA Earth Explorer Programme
  Now discarded
- Current activities in preparation of the FLuorescence EXplorer (FLEX) ESA Earth Explorer mission
  in Phase A / B1
- Preparatory activities for data exploitation of global time series of high resolution data within the Global Monitoring for Environment and Security (GMES) programme, including data assimilation of Sentinels data for land applications.
- TERRABITES – *Terrestrial biosphere in the Earth System*, Carbon Model Reference Dataset, Climate Change Initiative, Essential Climate Variables, Glob-data series, etc.

The meaning of EARTH SYSTEM MODEL

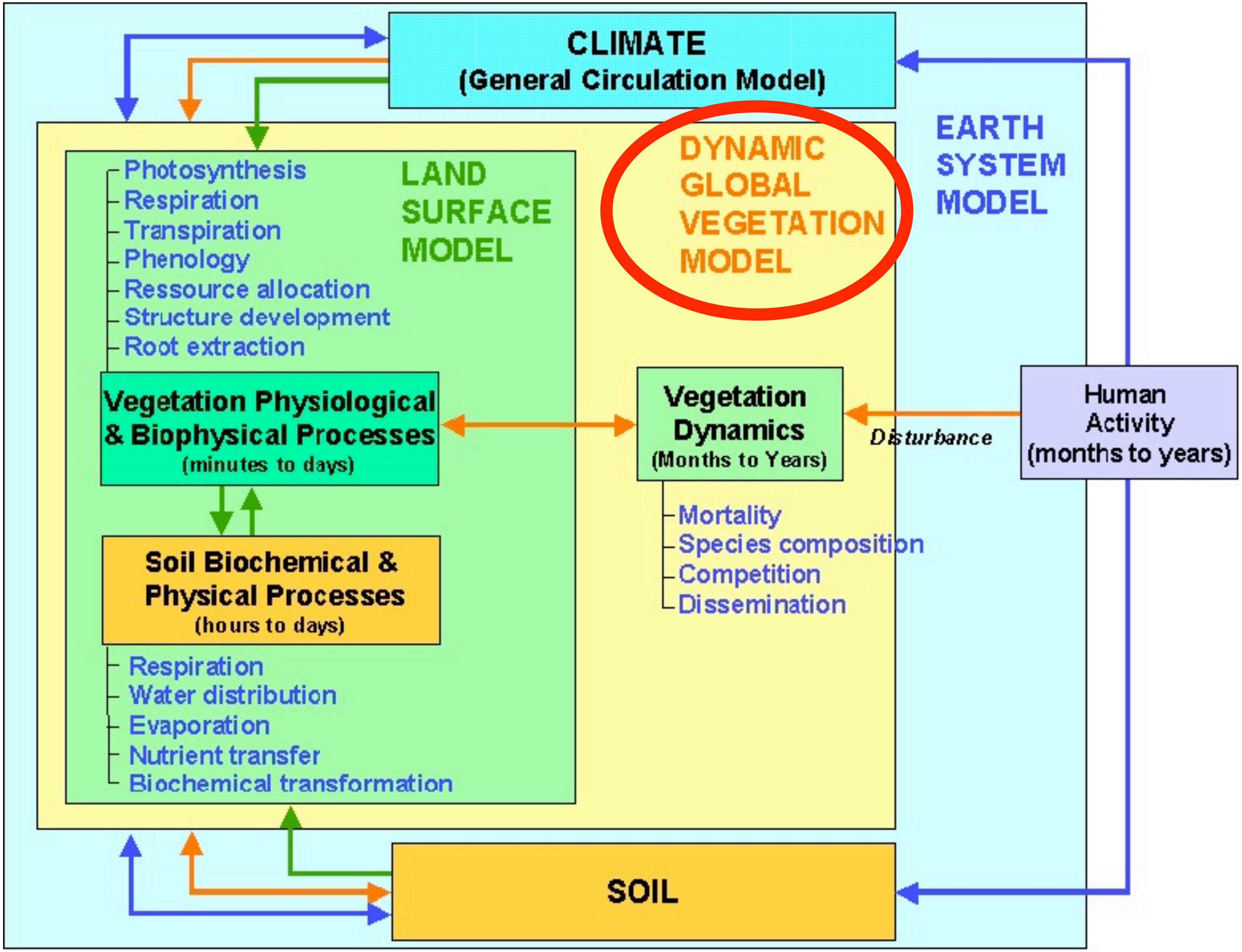
(a) Technology side

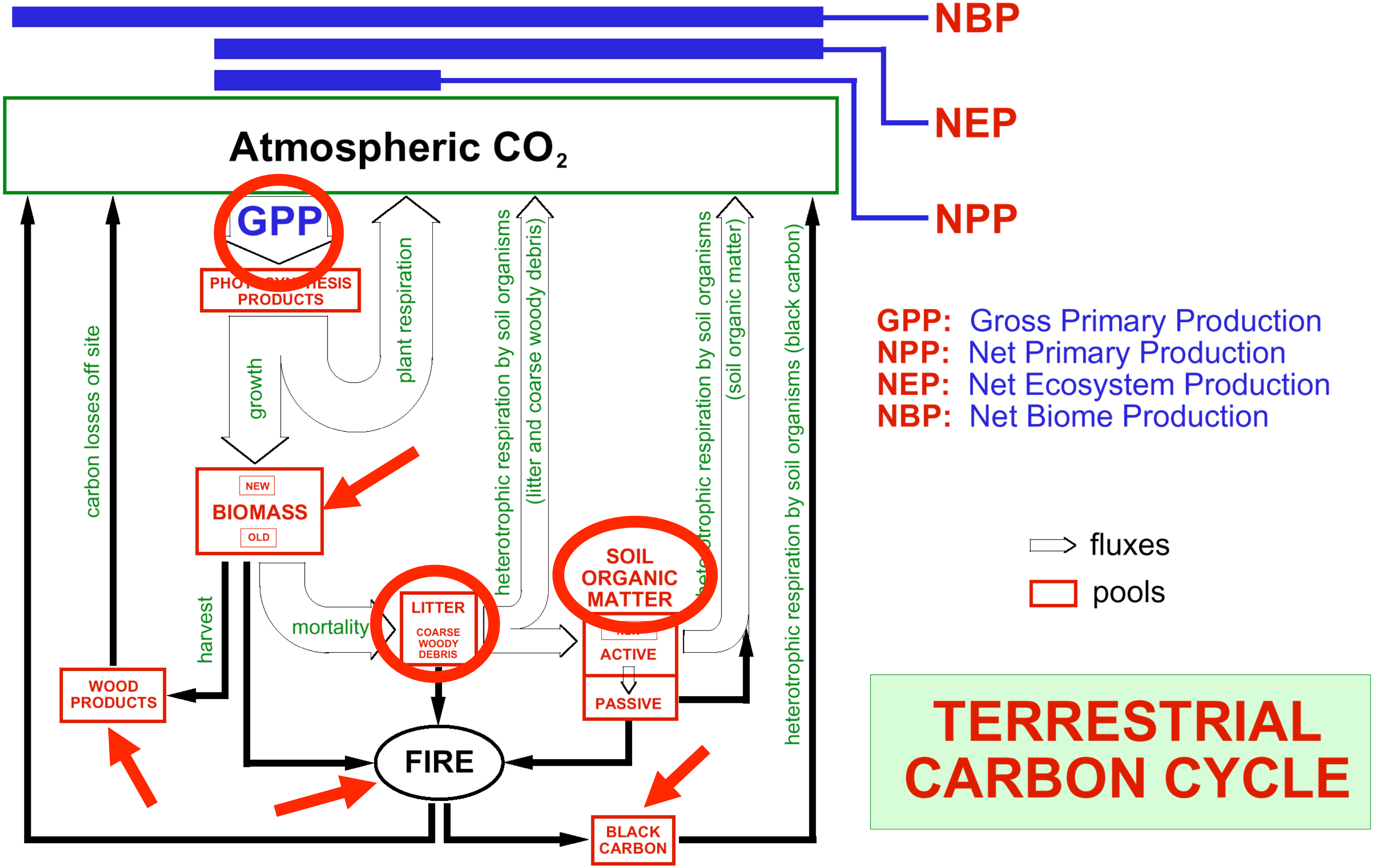
Big powerfull computers running monster programs and producing huge amounts of output data that are better visualised in nice 3D animations (vector/parallel machines, code optimisation, distributed computer nodes grid, Fortran 2000+)

(b) Science side

Trying to make a "Theory of Everything" about the Earth (including solid Earth: volcanoes, earthquakes, etc. Oceans: temperature, salinity, circulation, etc., Atmosphere: all physics and dynamical chemistry, but also Live: ***a dynamical model of the Biosphere***)

In practice, the real problem is to define an adequate parameterization for the actual available inputs !


CLIMATE
(General Circulation Model)
EARTH SYSTEM MODEL
DYNAMIC GLOBAL VEGETATION MODEL
LAND SURFACE MODEL
Photosynthesis
Respiration
Transpiration
Phenology
Ressource allocation
Structure development
Root extraction
Vegetation Physiological & Biophysical Processes
(minutes to days)
Soil Biochemical & Physical Processes
(hours to days)
Respiration
Water distribution
Evaporation
Nutrient transfer
Biochemical transformation
Vegetation Dynamics
(Months to Years)
Mortality
Species composition
Competition
Dissemination
Disturbance
Human Activity
(months to years)
SOIL



TERRESTRIAL CARBON CYCLE

Getting the whole picture:

(a) Photosynthesis / CO_2 assimilation

Light absorption by plants

Different use by the plants of the absorbed light

Changes in land-use & physiology (growth/senescence)

➡ **Imaging spectrometers VIS/NIR/SWIR + TIR**

(b) Biomass allocation / long-term carbon accumulation

Respiration terms for each biomass type (total biomass)

Net carbon accumulation (seasonal + multi-annual)

➡ **SAR (L-inf, P-pol), Canopy lidars, BRDF sensors**

(c) Atmospheric CO_2 concentration

Net CO_2 balance (bottom of atmospheric column)

+ CO_2 atmospheric transport

➡ **Dedicated atmospheric spectrometers + lidars ?**

Photosynthesis modelling approaches in LSM/GCM-DGVM

	POSITIVE	NEGATIVE
Biochemical	- Physical model (useful for climate change simulations at all scales) - Makes possible the explicit coupling of energy, water and carbon fluxes	- Computationally expensive for long-term climate simulations
Light-use efficiency	- Conceptual model (few parameters) - Interersting approach when APAR is measured (mostly over time scales of constant LUE)	- Empirical approach (useful for long timescales but accounting for LUE changes) - Not possible the explicit coupling of energy, water and carbon fluxes
Carbon assimilation	- Simplistic approach (useful for very long timescales) - To be used with coupled conceptual models	- Empirical approach (calibration needed for each environment) - Explicit coupling of processes not possible due to necessary large time steps

OPEN ISSUES IN LAND SCIENCE – Modelling aspects

- Model structure improvements:
  - parameterisation of surface heterogeneity
  - horizontal transport at the boundaries
  - vertical transport in 3D structures
- Coupling to ecological processes
  - phenology cycles / multiannual growth
  - vegetation dynamics (sucession, regeneration)
  - soil processes (decomposition, mineralisation)
- Coupling to hydrological processes
  - surface/sub-surface transport
  - river flow
  - lake/wetland dynamics
- Coupling to chemical cycles (CO_2, CH_4, N_2O, …)
- Link to atmospheric dynamics (wind at surface)

OPEN ISSUES IN LAND SCIENCE – Data availability

- Global data available mostly are of low spatial resolution, with limited capabilities to observe variables directly related to some key processes, though indirect observation is possible via the coupling of different processes through modelling.

- There is a definite need for global data at high spatial resolution (< 300 m) to be able to describe surface heterogeneity at relevant scales with adequate temporal resolution to describe dynamics

- Full spectral resolution (VIS, NIR, SWIR + TIR) highly desirable to constraint models with a full set of observations for each given model parameterization.

Unique information provided by HyspIRI:

Explicit mapping of <u>how plants absorb light</u>, as a function of the temperature of leaves

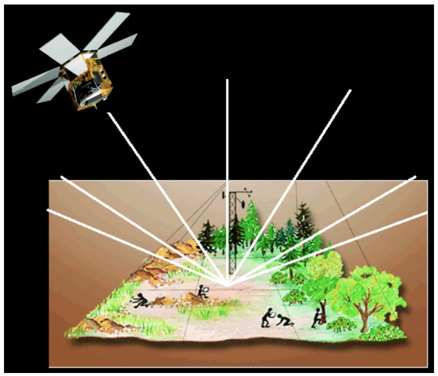
- *spectrally resolved PAR (400-700 nm)*
- *canopy chemistry and structural effects, decoupling non-photosynthetic elements*
- *high data quality is expected*

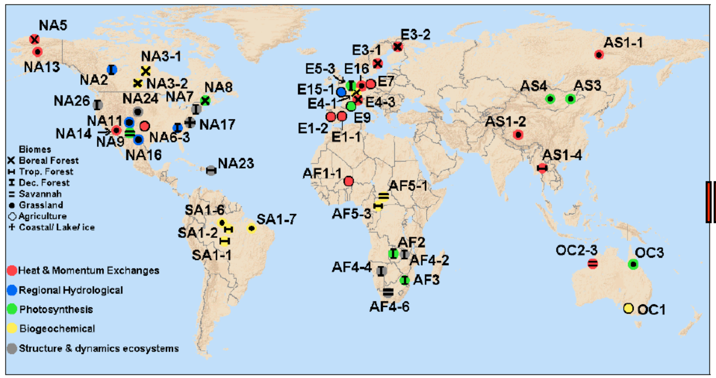
- **Monitoring vegetation changes (time series)**

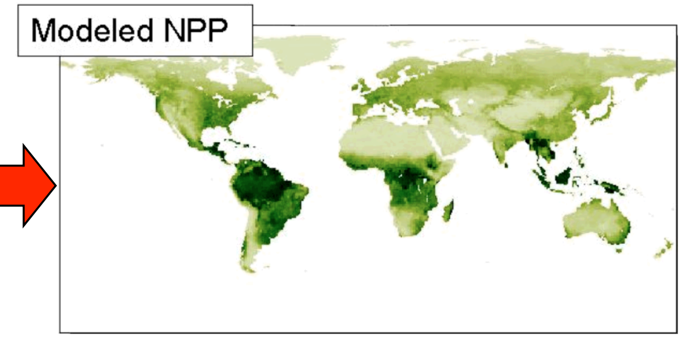
But we not only need to get <u>data</u> to be ingested in existing models but also to develop <u>models</u> that can ingest the new available data !

Different spatial sampling observational approaches:

(a) Discrete sampling of identified reference sites

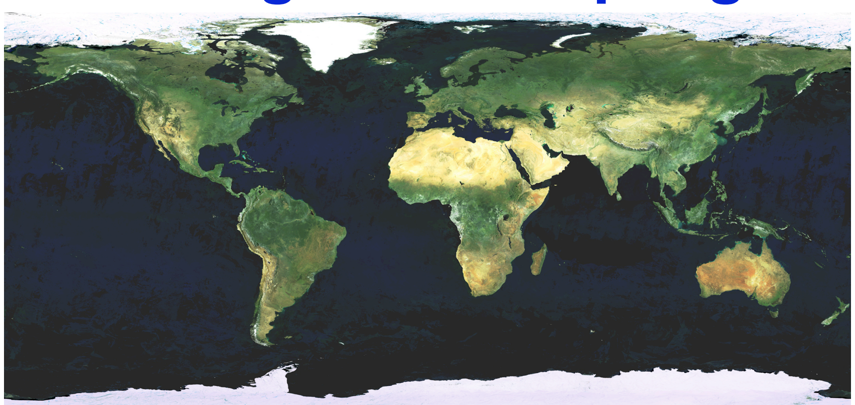


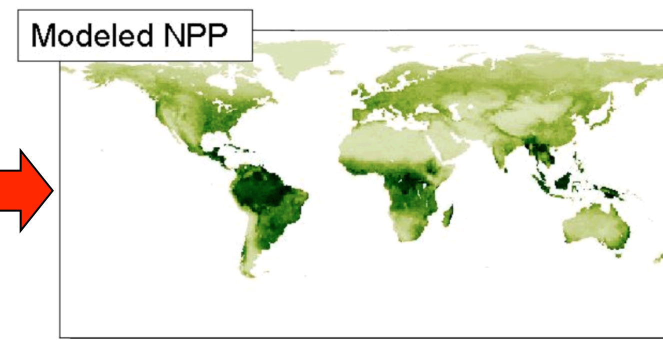




(b) Systematic global sampling

HyspIRI approach



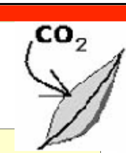


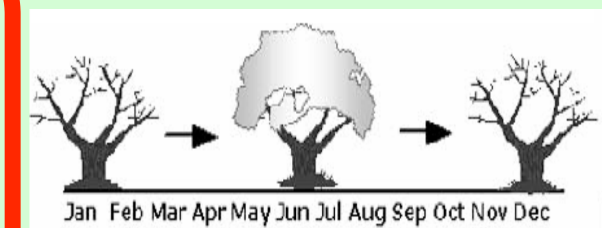
Temporal scales in DGVM

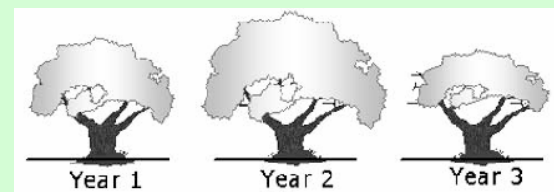
From 15-30 minutes time-step (to capture diurnal cycle) to long-time scale processes (centuries, millennia) both for past and future dynamics

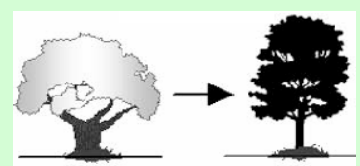
≥ 5 - 19 days — **Temporal scales resolved by HyspIRI** — **≤ 5 / 10 years**

Minutes / Months	Photosynthesis and leaf respiration
Minutes / Months	Growth respiration Stem and root maintenance respiration
Daily / Monthly	Phenology
Daily / Annual	Allocation
Monthly / Annual	Nitrogen cycle
Decades / Centuries	Competition between Plant Functional Types



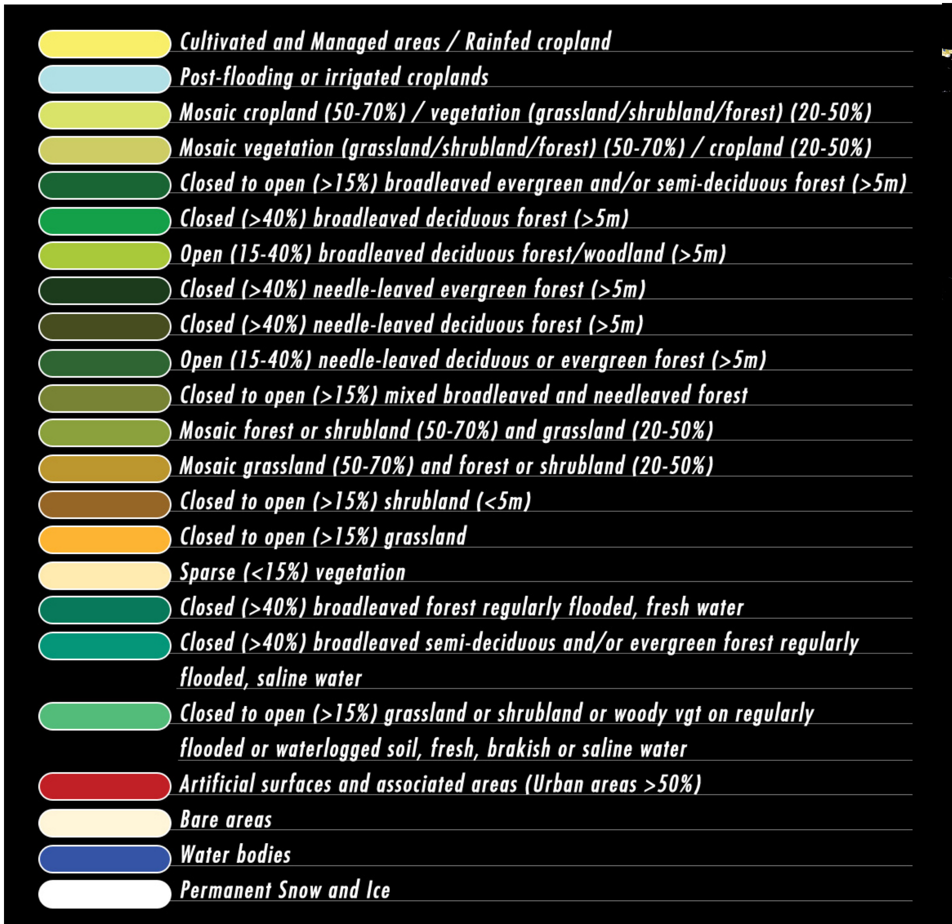


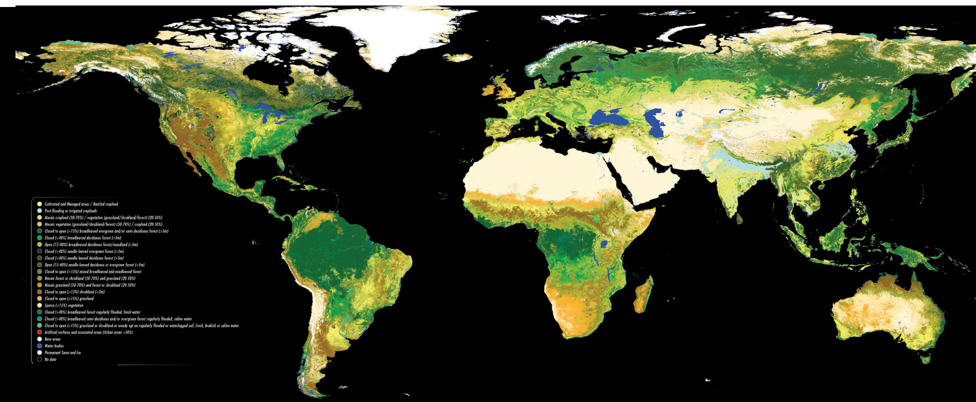




First approach:
LAND COVER MAPPING, CLASSIFICATION AND TABLES OF BIOPHYSICAL VARIABLES ASSIGNED TO EACH CLASS

Global land cover maps
Feature-Based Parametric Object Oriented Land Cover databases





→ Plant functional types and temporal profiles

Disturbances described by multi-annual classifications

Second approach:
RETRIEVALS OF BIOPHYSICAL VARIABLES AS DIRECT INPUTS TO MODELS

- Global spatially distributed inputs assumed necessary by most modeling approaches (APAR, LAI, fCover, Chl, temperature, etc.)
- Specific variables retrieved from remote sensing data used either for initialisation, forcing, updating or validation

Use of constrained minimization procedures that guarantee the minimal variation of model variables to produce the same output, and a robust initialization procedure of such variables (consistency even if model has global bias).

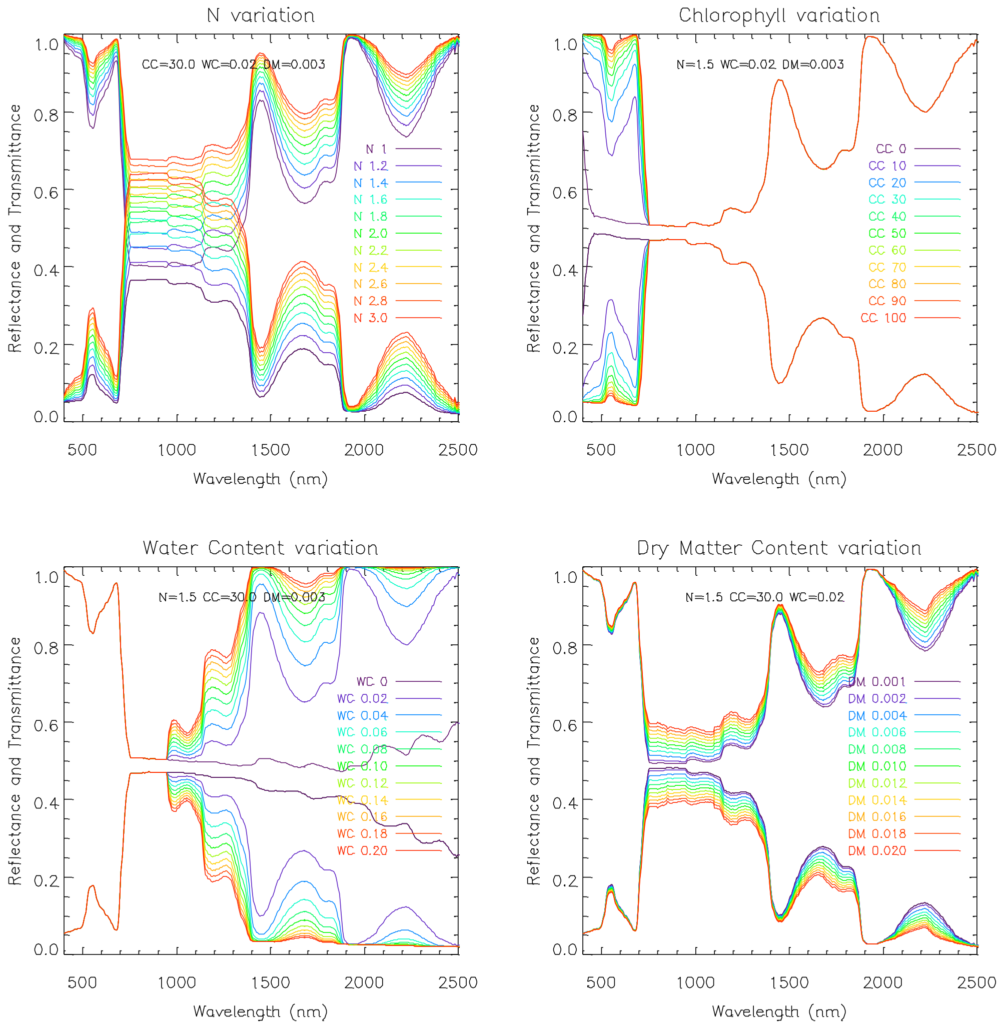
$$f(\overline{\mathbf{x}}) = \frac{1}{2}\overline{\mathbf{x}}^T \overline{\mathbf{W}}_{\mathbf{x}} \overline{\mathbf{x}} + \frac{1}{2}\left(\overline{\mathbf{z}} - \overline{\mathbf{H}}\overline{\mathbf{x}}\right)^T \overline{\mathbf{W}}_{\mathbf{d}} \left(\overline{\mathbf{z}} - \overline{\mathbf{H}}\overline{\mathbf{x}}\right)$$

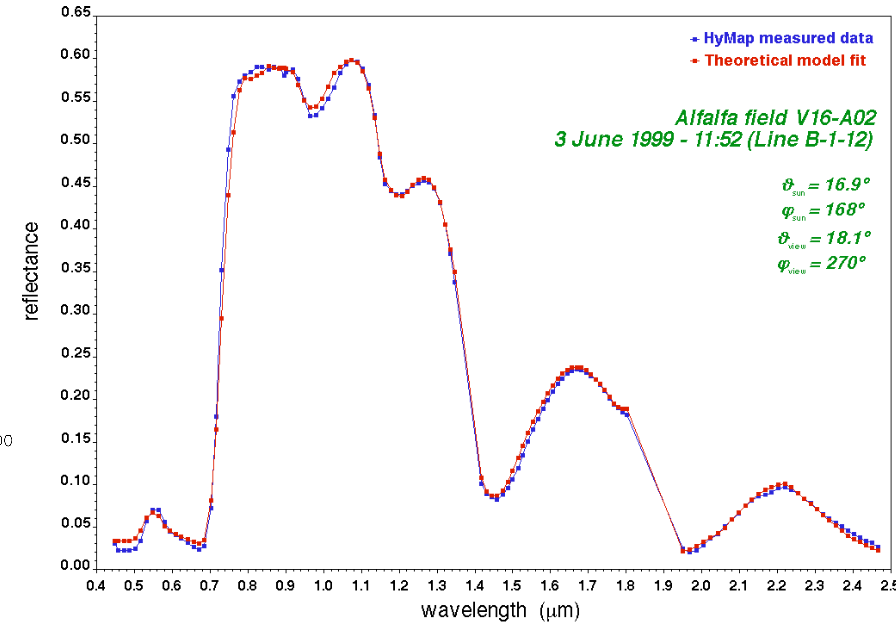
Open issues:

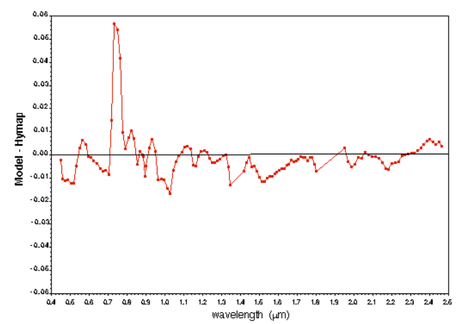
- Specific Leaf Area (currently normally PFT fixed) is a key parameter that need spatialization (current parameterizations assume carbon derived from SLA).
- Non photosynthetic elements in canopy structure not yet described (i.e. celullose, lignin)

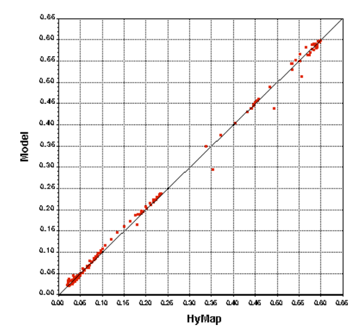
→ **Potential for new variables to be provided by HyspIRI**

How well the spectral reflectance signal is understood?









Third approach:
DIRECT ASSIMILATION OF RADIANCES/REFLECTANCESINTO MODELS

- The function that relates the set of observables to the state variables -forward operator or mathematical model- is not always well defined; variables tend to have different meaning.
- For instance, LAI is an important variable in the DGVMs, but remote sensing products not yet used properly used to inconsistency (green/total, true/effective, clumping)
- Light absorption: chlorophyll content used instead of APAR (APAR computed instead of input) new remote sensing products are necessary.
- Consistent description canopy structure (used in photosynthesis modules to separate sunlit and shadowed leaves) and absorption by photosynthetic pigments and by other non-photosynthetic elements.

The physical laws that relate the state variables and the observables are rather empirical in most cases (weak conservation laws).
Direct data assimilation is a tendency to avoid problems and inconsistencies.

Is it possible to assimilate TOA radiances in Dynamical Global Vegetation Models?

- In principle yes, if one can deal with atmospheric effects (aerosols, water vapour, ozone), but dynamical effects are too challenging (i.e., statistical cloudiness versus actual clouds). Assimilation of TOA radiances in dynamical models is a challenge.

- A more realistic approach is to assimilate normalized time series of surface reflectance (enhancement in the radiative transfer component of the models is needed).

- An even more realistic approach is to assimilate maps of surface variables consistently retrieved.

- An even more realistic approach is to assimilate 'constant' (or with low time variation) surface parameters instead of relying on fixed parameterisations (i.e., V_{max})

CURRENT TRENDS IN GDVMs – 1 : Resolutions

GCMs typically use 15-30 min as time-step, DGVMs use time-steps from 30 min to one day (up to a month).

GCMs operate with resolutions in the order of 100-500 km resolution, DGVMs use resolutions in the order of 50 km.
Processes on a scale < 1 km (including vegetation patterns and wetlands, permafrost, urbanization, etc.) are parameterized as sub-grid scale processes (not explicitly resolved).

Spatial resolution is an issue. Tiling (fractional horizontal cover) and spatial sampling techniques are common approaches. The alternative to go for fine resolution without tiling is being seriously considered, at least for test relevant scenarios of using GDVM outside GCMs.

The assumed sub-grid scale parameterizations are not thoroughly calibrated. Explicit modelling of traits (explicit spatially distributed data) is an emerging approach that definitely needs the link with global datasets derived from remote sensing data.

CURRENT TRENDS IN GDVMs – 2 : Parameterizations

- The key problem right now is the large number of parameters and the large uncertainty in such parameters, which limits the capability to run predictive analyses based on perturbations of free model parameters to test future climate scenarios including plant adaptation / acclimation to climate change.
- The only way to have better confidence is to run models over "current" datasets to get good model parameterization to run future predictions.
- Model intercomparison (C4MIP, etc.) is a common approach to estimate structural uncertainty in the models (driven by model parameterization) and benchmarking are designed to indicate "best" parameterizations strategies.

But a *reference dataset* is needed which is: global, high spatial resolution, spectrally complete, good temporal resolution, covering several years to describe several seasonal cycles

NOTE: Reference datasets are needed to fix parameterizations, not necessarily as "inputs" to run the models.

THE WAY FORWARD:
What activities are needed to achieve these goals?

- The DGVM modellers are already too busy with model improvements in other aspects and will not adapt their models to ingest these new type of data.
- Direct radiance/reflectance data assimilation is an adequate efficient way, but model adaptations are needed.
- Remote sensing specialists with some background on modelling are in a better position to establish the link between data and models.
- The HyspIRI community must be active developing the necessary modelling and data assimilation tools.

Thank you !