DA for land surface studies in the Sentinel era: how can we deliver?

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June 2014

National Centre for Earth Observation
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Outline

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EO data for the land surface

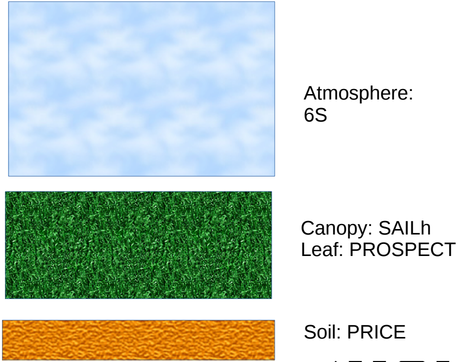
- The land surface is highly dynamic and directly affected by human activities
- Need to understand vegetation role in the C cycle
- EO data is the only practical way to achieve this on a timely, global scale
- Recognition that consistent, best possible estimates are required $\rightsquigarrow$ ECVs/CCI
- Sentinels/GMES
  - Long term monitoring capability
  - Suite of spaceborne sensors
  - **Challenge:** How to combine data from different sensors, and still be consistent and traceable?

Complications

- EO data is an indirect measurement of land surface characteristics
- We need robust physical models to interpret these data that coherently deal with

- Atmospheric effects
- Canopy structure
- Leaf biochemistry
- Soil, Snow, . . .

- We also need to deal with gappy time series (clouds...)
- EO information content is fairly poor



The value of an observation: A typical (synthetic) example

The setup

- LandsatTM spectral/angular sampling
- Green canopy. LAI 4.2
- e.g. lush & green wheat crop
- Noise: typical/optimistic
- Use a typical RT model (PROSAIL) for the inversion
- No "model noise"

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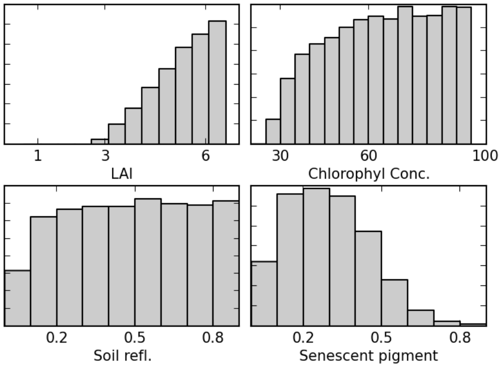


Ill-posed problems

- Monitoring vegetation using EO data is an ill posed problem
- Only way to solve it is to add extra constraints $\rightsquigarrow$ prior information
- We choose 4DVAR with a weak constraint for flexibility

$$\min_{\vec{\mathbf{x}}} J(\vec{\mathbf{x}}) = J_{prior}(\vec{\mathbf{x}}) + J_{obs}(\vec{\mathbf{x}}) + J_{model}(\vec{\mathbf{x}}) \quad (1)$$

- Use gradient descent techniques $\rightsquigarrow$ Need $\partial J(\vec{\mathbf{x}})/\partial\vec{\mathbf{x}}$

DA and EO

- For vegetation...
  - Poor models of spatial+temporal evolution of veg parameters of interest
  - DGVMs limited $\rightsquigarrow$ spatial resolution, assumptions. . .
  - . . . but also want to be independent of big models for some applications
  - Use Spatial/temporal regularisation
  - Encode a belief in smooth trajectories/exploit correlation.
  - Weak constraint: do not fully trust the smoothness expectation.

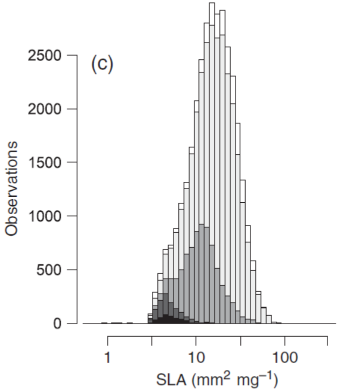
Outline

DA, EO data and the land surface in the Sentinel era

- Important increases in data volume
- State representation at a higher resolution
- DA techniques are computationally expensive
- 4DVAR can require a lot of iterations
- ... particularly if your physical models are complex
- It would appear that we have more (data) than we can chew!

Better priors: Exploit trait databases

- Placing tighter priors to simplify the problem
- Plant traits databases (e.g. TRY) $\rightsquigarrow$ global data on plant structure & biochemistry.
- Traits relate to RT model parameters (beware of effective params!!)



Faster ObsOps: RT models are slow!

- Typical RT models are too slow. Pragmatic solutions:
  - Look-up tables
  - Neural networks

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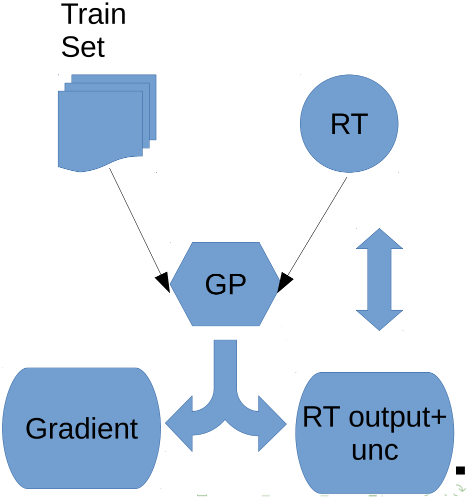
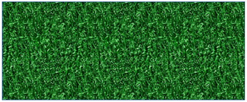
- What about emulators?
- (Very) Fast Statistical approximation to full model
- Estimate model output + uncertainty
- Estimate model gradient ⇝ no adjoints needed



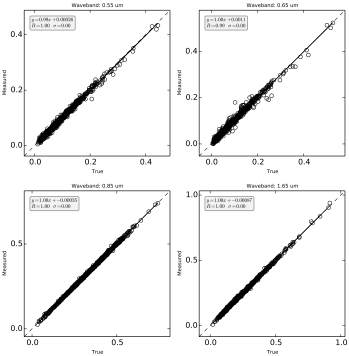
Emulators for SPOT4 data: TOA reflectance

Atmosphere:
6S



Canopy: SAILh
Leaf: PROSPECT

Soil: PRICE



Emulating Take5 acquisition geometries over the Provence/La Crau site (Feb & Jun)

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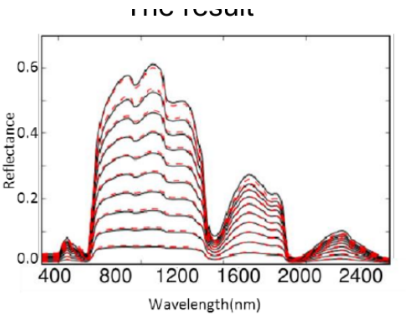
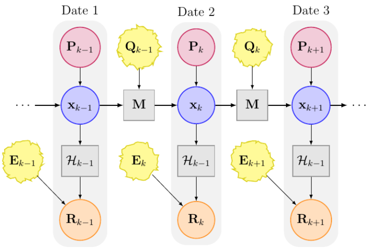
Full spectrum examples



- Through an orthogonal trasformations

Dealing with massive state spaces

- Dealing with space/time in current form impossible
- E.g. 120x120km area, 20m resolution $\underbrace{6000}_{Rows} \times \overbrace{6000}^{Cols} \times \underbrace{180}_{Days} \times \overbrace{10}^{Params} \sim 6.5 \cdot 10^{10}$



1. Sequential approach: feed posterior to prior of next date
2. Only need inverse covariance $\rightsquigarrow$ Hessian
3. The Hessian (using regularisation only) is very sparse
4. Good prior esitmate benefits cloud/shadow detection, atmospheric correction and disturbance monitoring

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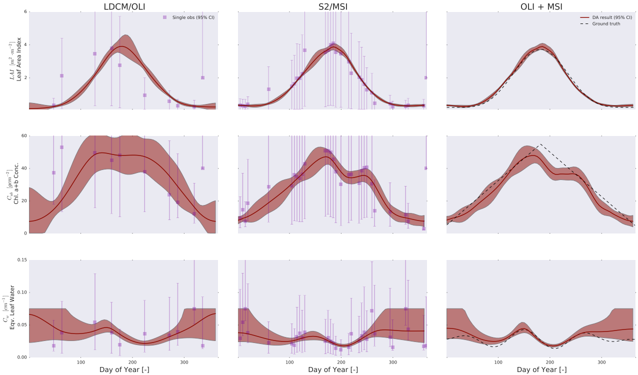
Example: S2 + LDCM simulation example

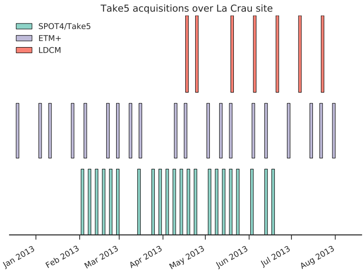


Result of synthetic experiment showing **single observation inversions (dots)** and **DA results (full line)**. Reported uncertainties are 95% CI.

Some nice data & a very nice tool

Take5

- Acquire data over 45 sites
- . . . with 5 day revisit period over ∼ 5 months



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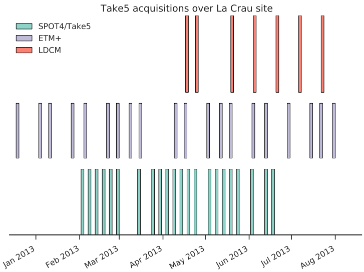
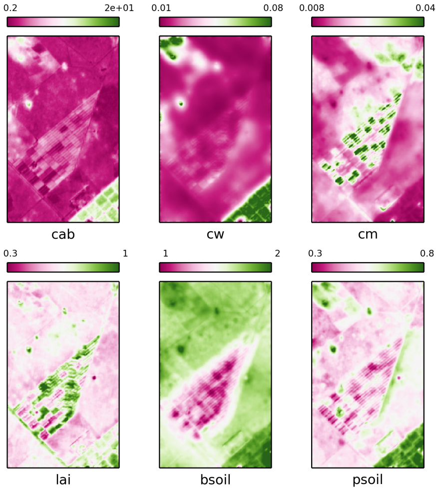


eoldas_ng

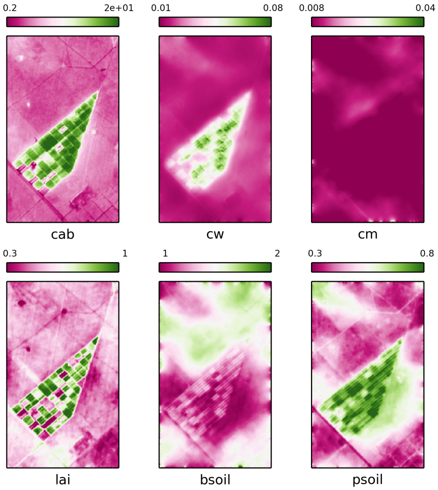
- Python tool for Variational DA
- Flexible & easy to use
- Developed for a number of ESA-funded projects
- Includes most of the stuff in this talk

Take5: Spatial regularisation & TOA radiance DA



La Crau, 13.02.2013

Testing the prototype on Take5 data



La Crau, 13.06.2013

Outline

Conclusions

Coping with the data deluge, while still being rigourous:

- Use parsimonious "models" for space/time regularisation
- Trait data useful for better prior definition
- DA approaches need to scale to very large problems
- Emulation might not be fast enough. Need to explore:
  - Pre-conditioning
  - Local linearisations
  - Projections into sparse spaces and solving there
    - Solve the problem in an equivalent smaller space
    - EOF/PCA methods
    - Wavelets

Collaborators: T Quaife (UoR/UK), P van Bodegom (VUA/NL), T Kaminski (FastOpt/DE), N Gobron (JRC/EC), M Chernetskyi (UoJ/DE)

LAI trajectories from several DGVMs over European site