Fail-safe Index Insurance without the Cost: A Satellite-based Conditional Audit Approach

Jon Einar Flatnes & Michael R Carter***

*The Ohio State University
**NBER & University of California, Davis
***BASIS I4 Index Insurance Innovation* Initiative

Global Index Insurance Conference Academic Side Event
Paris

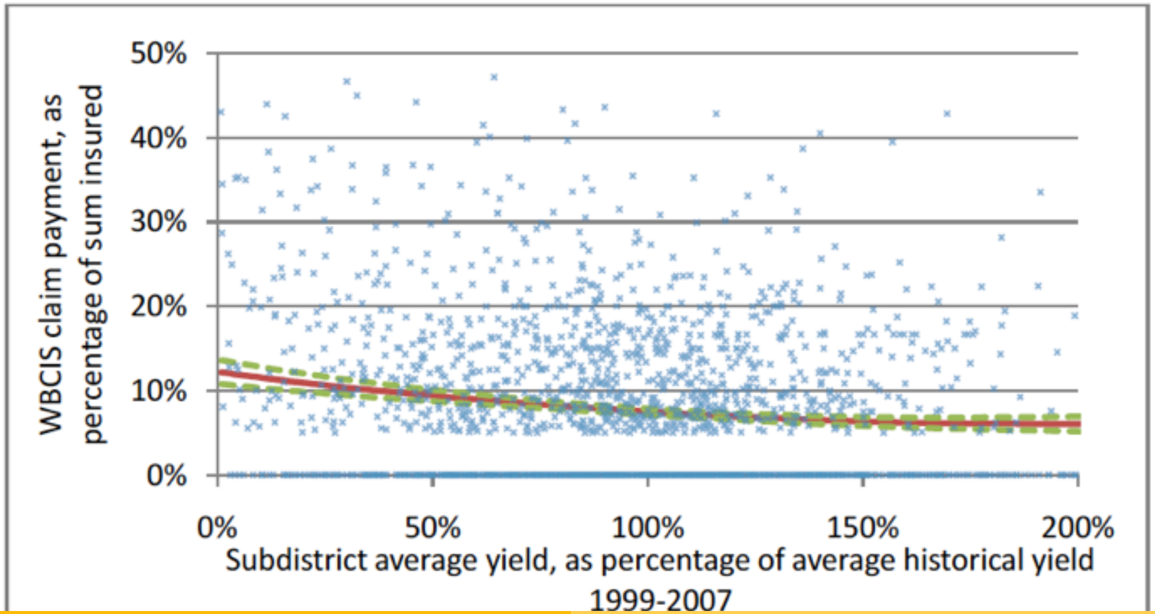
September 15, 2015

Removing Risk through Index Insurance

- Risk in agricultural systems can have devastating effects on the livelihood of smallholder farmers and hampers investment in risky but potentially profitable technologies
- Individual indemnity insurance is fraught with problems of moral hazard and adverse selection Index insurance solves these problems by basing payouts on an index that cannot be influenced by individual outcomes,
- But index insures only (at best) tackles covariant risk
- Area yield most promising as can cover multiple sources of covariant risk
- Note that what appears as covariant risk depends critically on scale of index

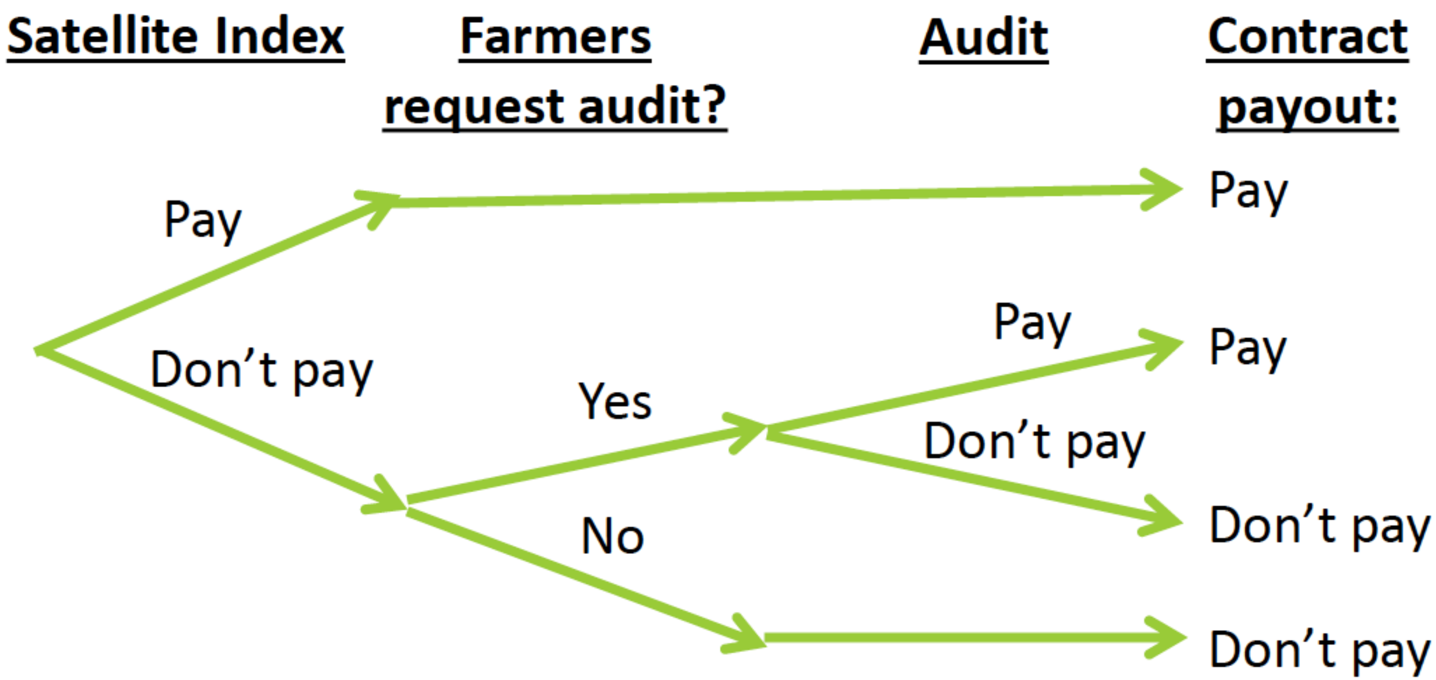
Existing Alternatives to an Area Yield Contract are Often Poor

- But: Data on area yields are rarely available for small-scale agriculture in developing countries; collecting it would be expensive
- Instead, most index insurance contracts are based on a weather index (typically rainfall)
- Weather contracts typically provide poor coverage for farmers due to high basis risk



Satellite-based Conditional Audit Alternative

- The primary index is based on (inexpensive) satellite data
- If the satellite index does not pay out, an audit can be invoked at farmers' request (related idea piloted in Ethiopia by Hill *et al.*).
- The result of the audit will determine payouts
- Incentive compatible penalties to prevent



Satellite-based Conditional Audit Alternative

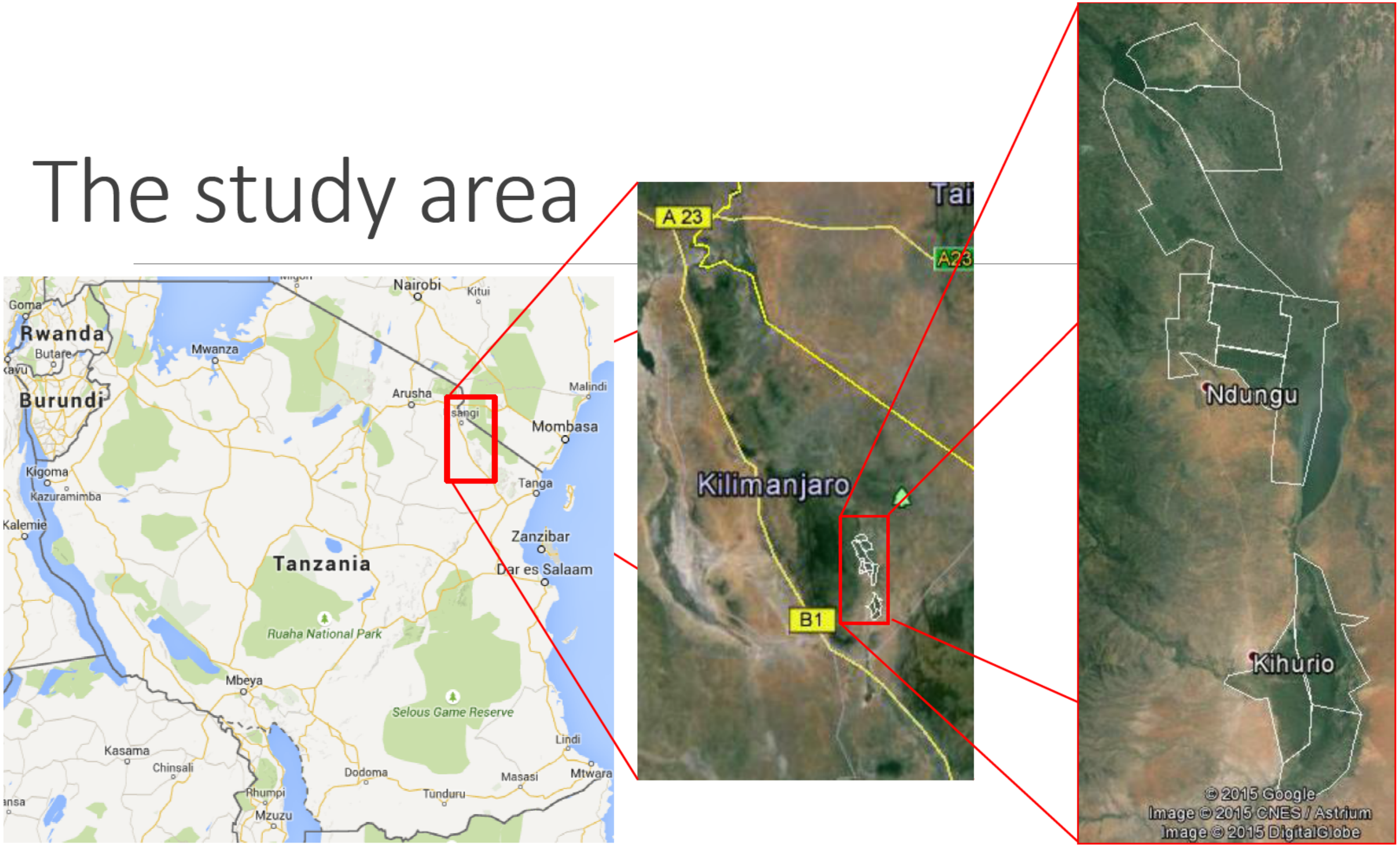
- For this audit model to be cost-effective, need reliable yield prediction primary index (otherwise, audit every year!)
- Satellite-based measures seem promising:
  - High-resolution (between 250 and 1000 meter pixels),
  - High-frequency (daily)
  - Publicly available (free-of-charge) for the past 13 years
  - Variety of measures to predict bio-mass & vegetation health:
    - Normalized Difference Vegetation Index (NDVI): measures the intensity of green vegetation
    - Evapotranspiration (ET): measures the amount of evaporation and plant transpiration and is related to crop health; estimate with composite satellite measures
    - Gross Primary Production (GPP): is the amount of chemical energy as biomass that primary producers (plants) create in a given length of time; also estimable with satellite measures

Example of Satellite Data

Satellite map of area around Ndungu village, Tanzania

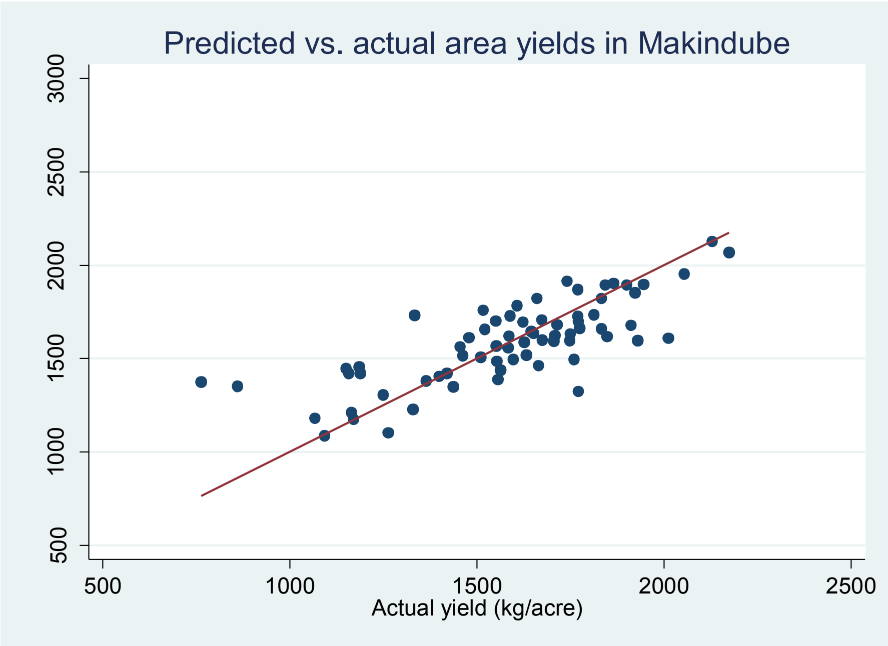
NDVI map of the same area before harvest (18 Feb 2012 - 4 Mar 2012)

Designing Audit-based Contract for Rice farmers in Northern Tanzania



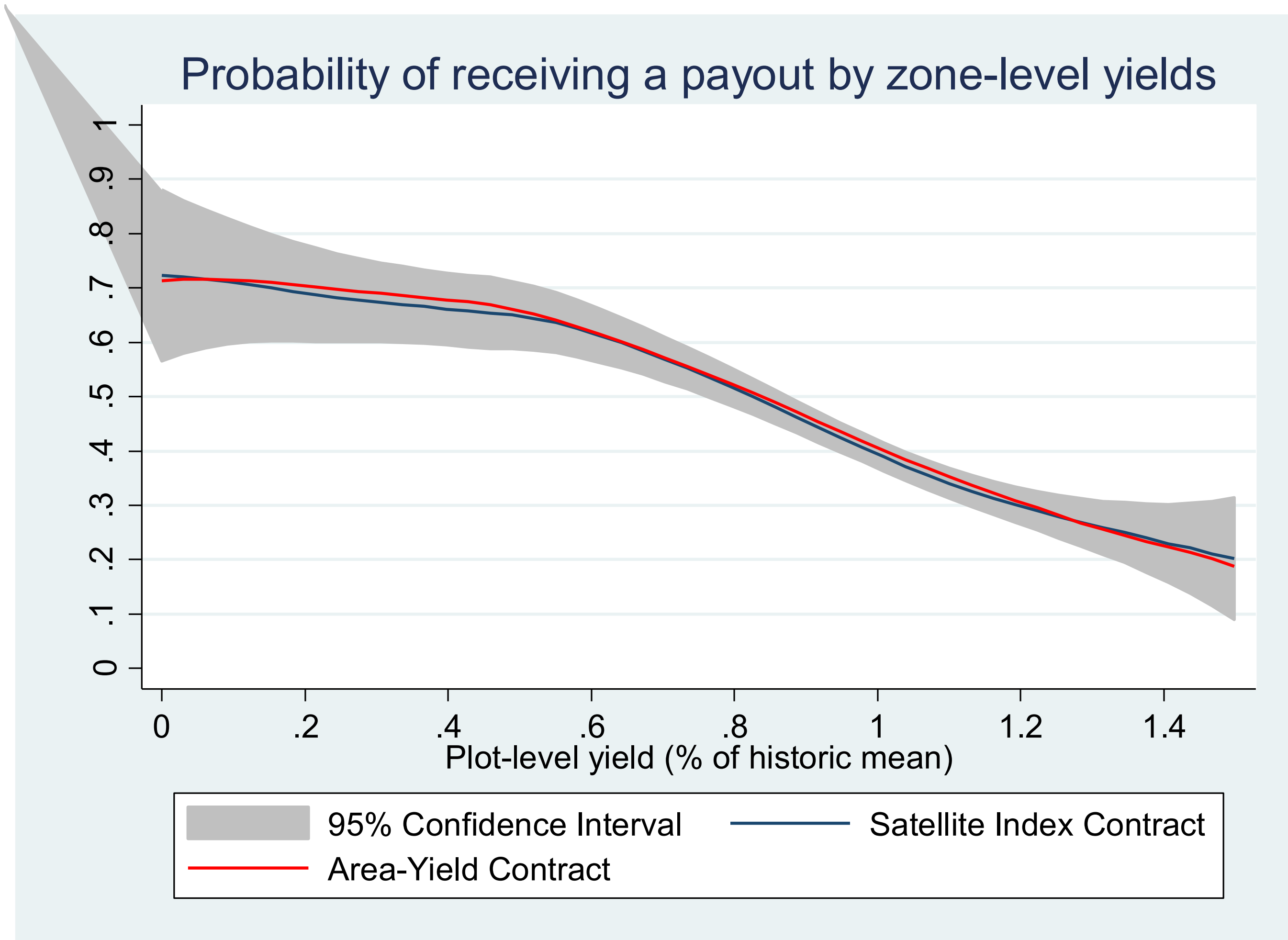
Village-level Area Yield vs. Optimized Satellite-based Contract

- For each small area ("village"), we collected 10 years of retrospective data on yields
- Best satellite predictor of village yields proved to be based on 'Gross Primary Production' (based on EVI, FPAR & LAI)
- Let's compare this (cheap to administer) satellite based index with an (expensive) village-level area yield contract:

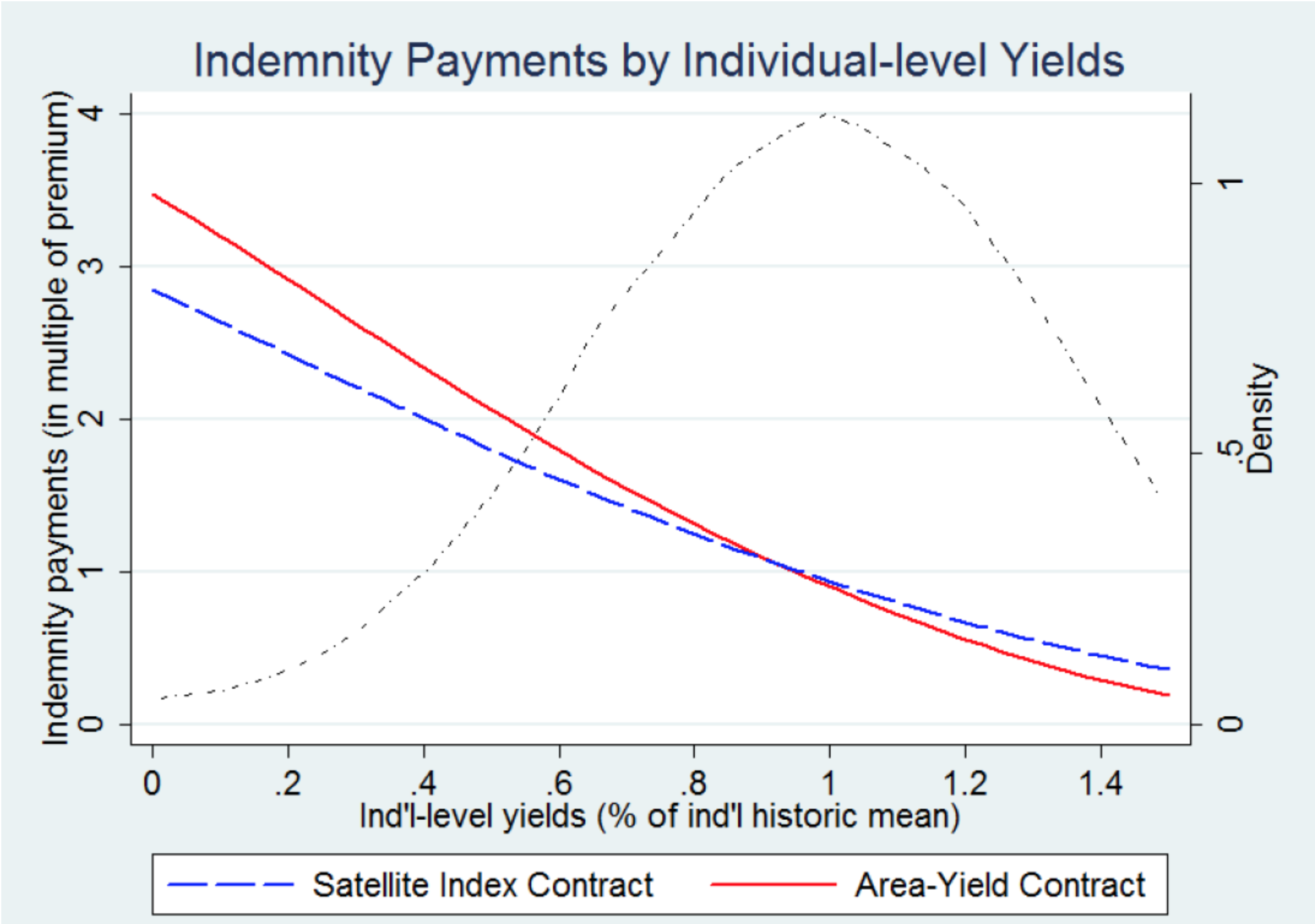


A "Will I get Paid" Probability Measure

- Consider a contract that pays anytime either measured or satellite predicted village yields fall below average:

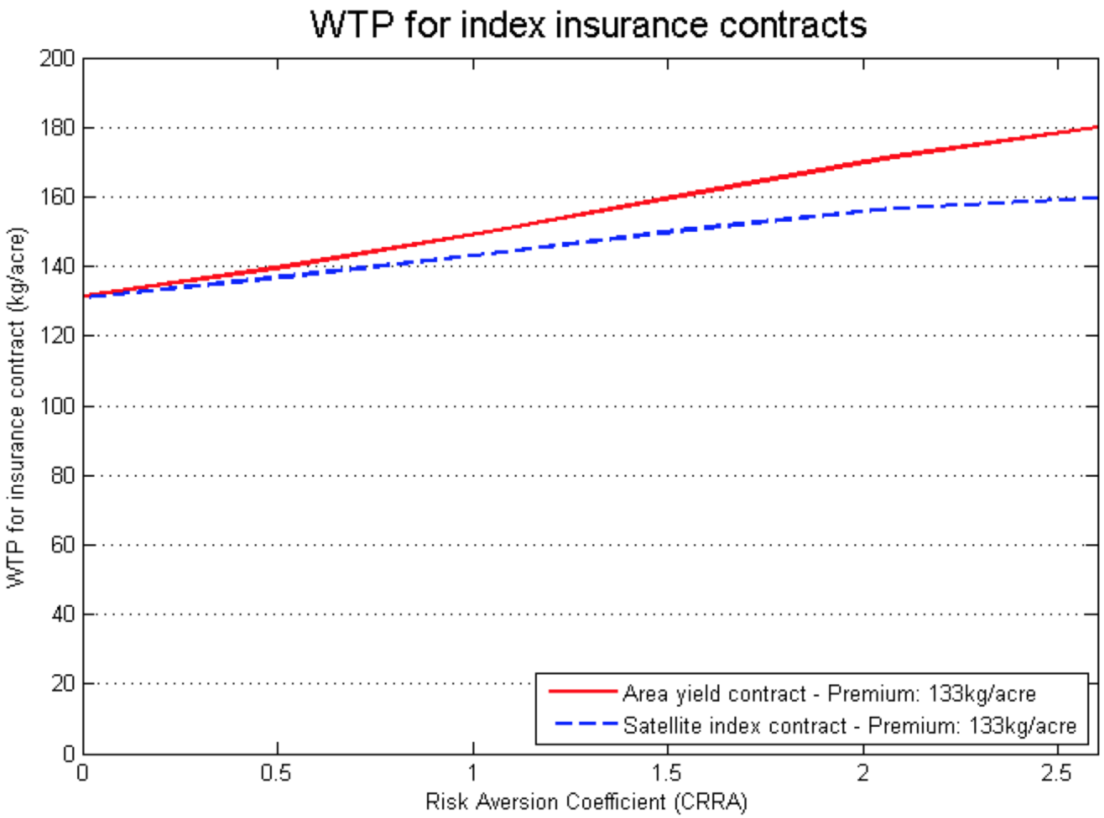


A "How Much will I be Paid" Measure



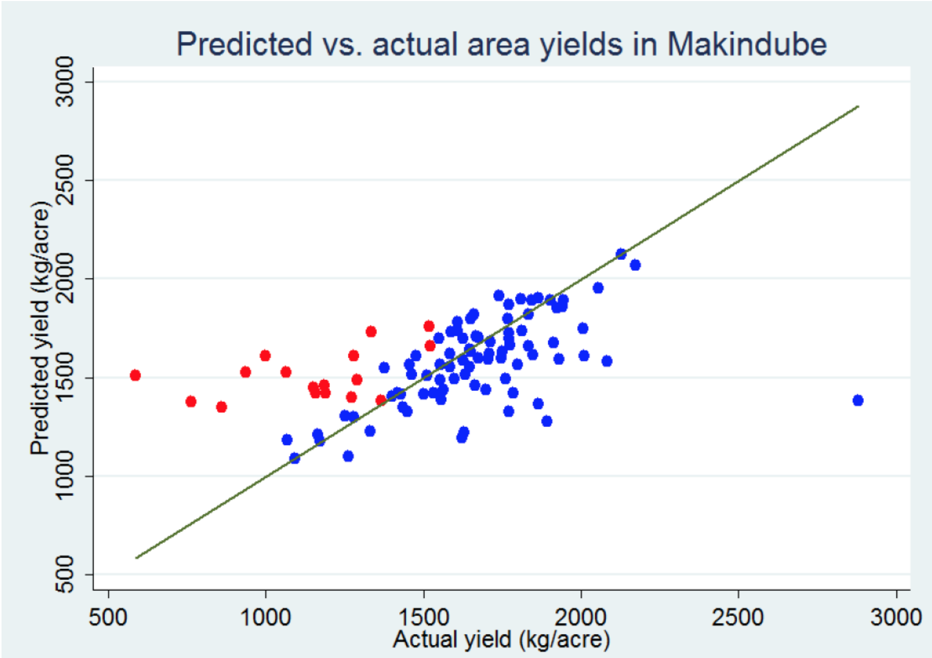
Reservation Price Quality Measure

- Actuarially fair prices for these contracts are 130 kg of rice per-hectare insured
- Unrealistically, assuming no local risk sharing
- Minimalist Quality Standard: Reservation Price > Market Price of Contract



Can We Do Better with an Audit Rule?

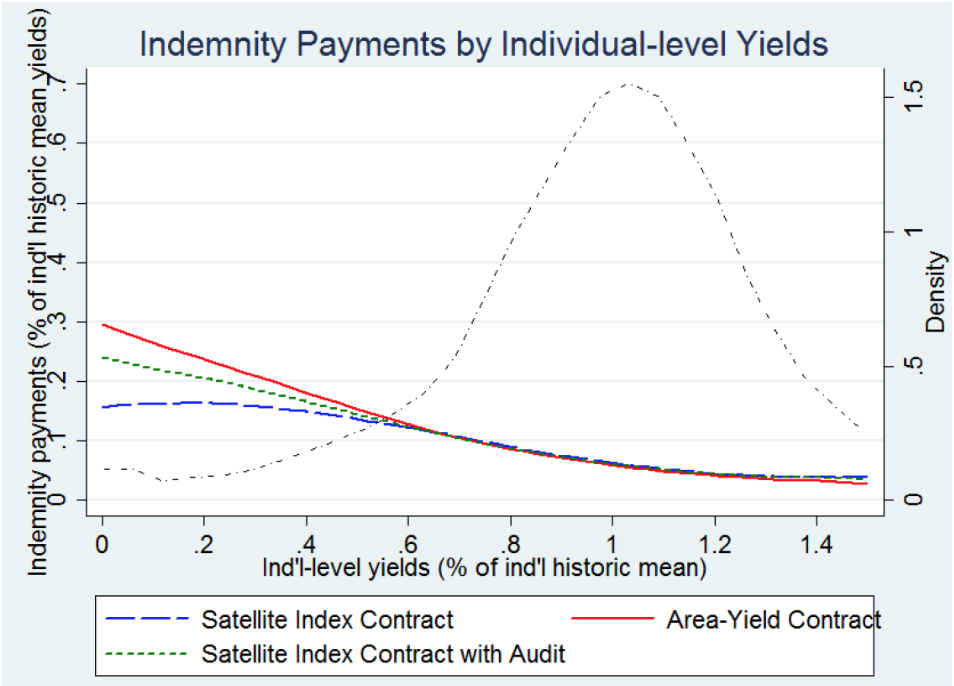
- Can see that the satellite does well separating good from bad, but has trouble distinguishing quite bad from slightly bad



- What if we followed Ruth Hill's model & proposed an audit scheme with:
  - Agreed upon crop cut methodology at village level
  - Incentive compatible penalties to prevent unnecessary audits

Can We Do Better with an Audit Rule?

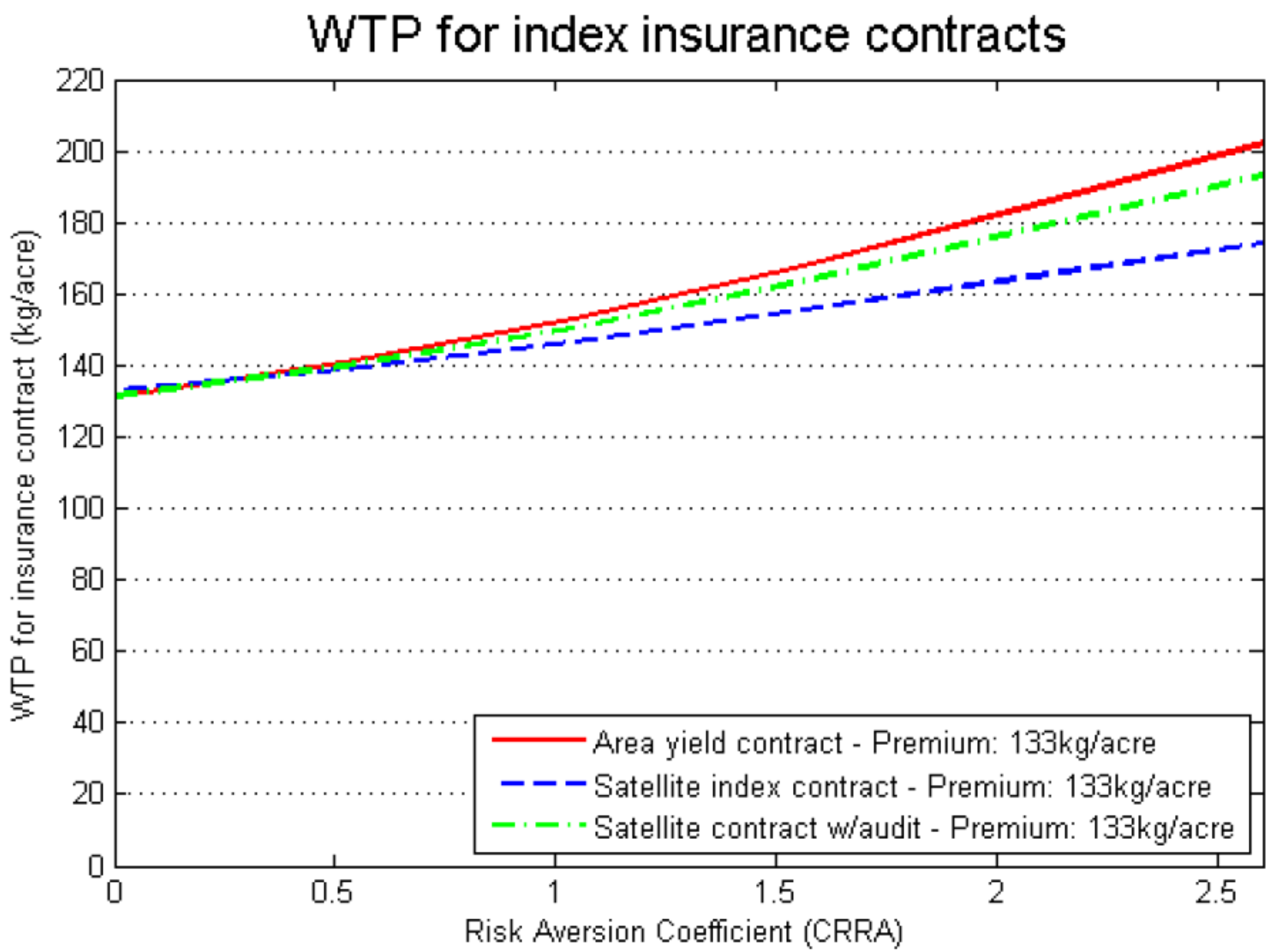
- Assume that audits only requested when predicted yields are 5% below actual village area yields
- 17% of the time audits will take place



- Shadow price will be close to pure area yield insurance
- Data collection costs will only be 17% of those under area yield!

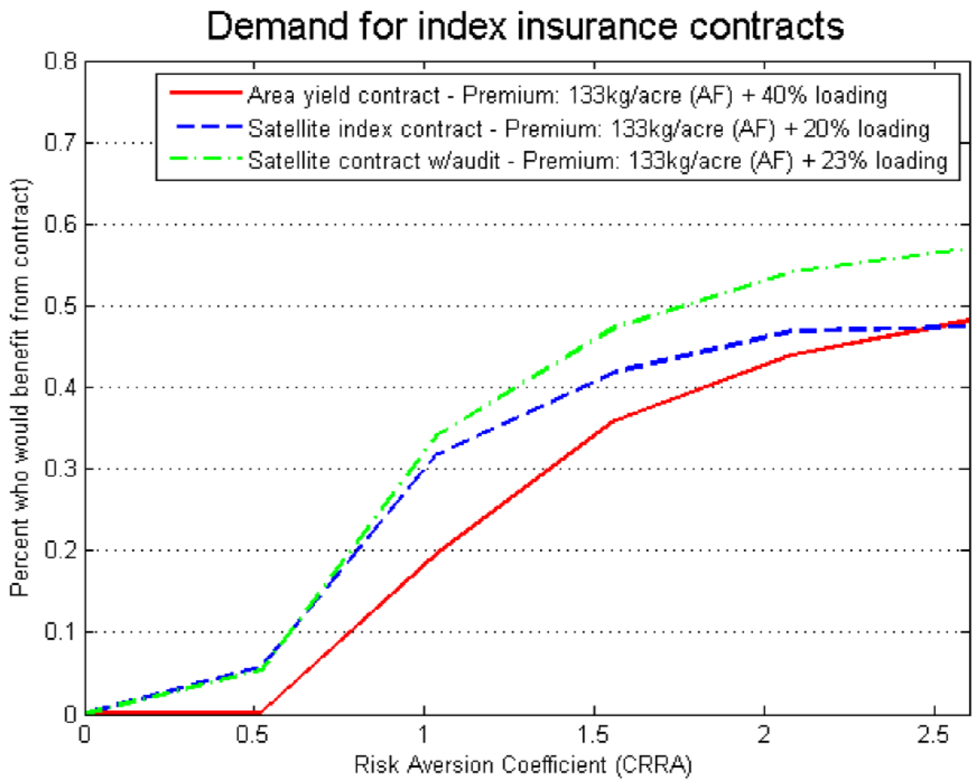
Reservation Price Quality Measure

- Adjust strike point so that audit-based contract has the same actuarially fair price



Predicted Demand for Alternative Contracts

- Consider now that the costs of the different contracts differ (area yield > audit > satellite)



Conclusions

- Audit-based contracts appear promising as a way to repair the Achilles heal of index insurance
- In particular case of Northern Tanzania, data suggest that an audit rule can be cost-effective and would meet with greater demand than alternative contracts
- Need still to further explore reliability of satellite-based measures in other environments
- New work in Nepal and the Dominican Republic is adding to our knowledge in this area

Index Insurance in Agriculture: Stakeholders Expectations & Optimal Design

GIIF Conference, Paris – September 16, 2015

DIDIER FOLUS, CEROS

CONSTANCE COLLIN, CEROS & PACIFICA

Presentation

1. Index Stakeholders Expectations
2. Insurance Index Overview in Agriculture
3. Relevance of the Index as an Asset Class
4. Perspectives

1. Index Stakeholder Expectations
1.1. Crop Yield Risk Nature

CROP YIELD RISK

Yield Fluctuation:
- Weather conditions (hail, drought…)
- Geo-political conditions (war…)
- Farmer's know-how (fertilizer, irrigation…)

Characteristics:
- Downside & Upside
- Systemic component (drought)
- Measure not so simple:
  - Traditional (adv. selection, mor. hazard) (Just & Calvin, 1993)
  - Index (basis risk)

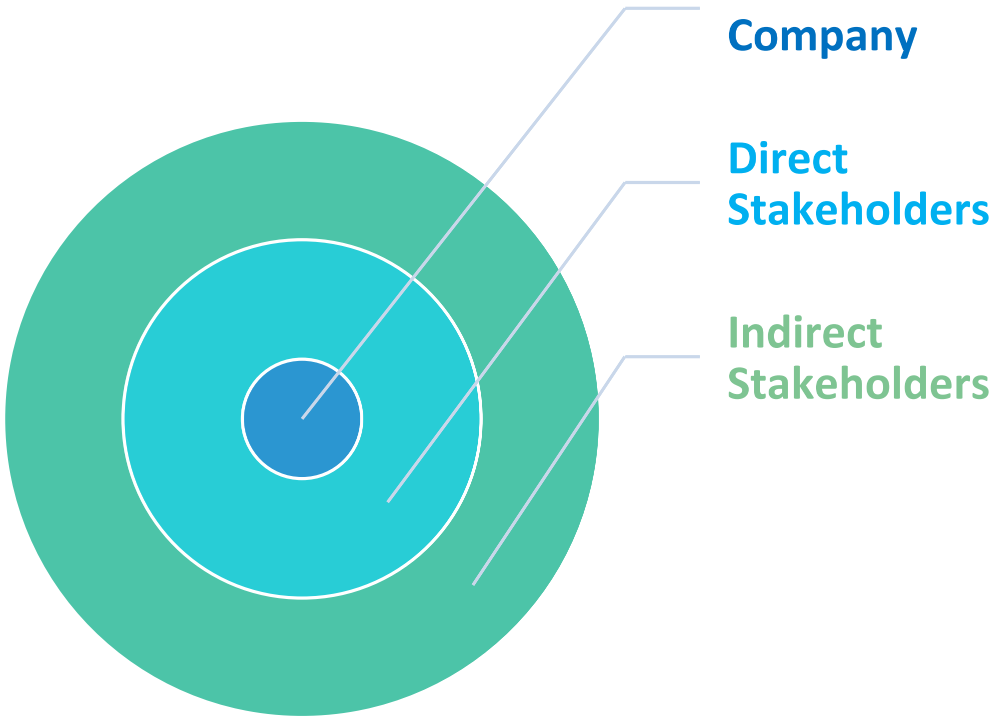
INSURABILITY (INDEX)

Risk mitigation difficulties:
- Index data availability
- Index statistical behavior
- Non-recourse

Pooling arrangement only ?

Support & hedge from:
- State
- Reinsurance company
- Investors

1.2. Insurance Company Stakeholders



Direct Stakeholders:

- Farmer, as coverage-taker
- Insurance marketer, as risk-trader
- Index provider: risk-assessment

Indirect Stakeholders:

- Agricultural trade association
- Regulatory body: authorization & solvency rules
- State: government grants & guarantee
- Reinsurance company, as risk-hedger
- Investors: alternative to reinsurance

1.3. Direct Stakeholders Expectations

Farmer: *product value*

- Increasing specialization, maintaining financial leverage (Barry & al., 1992)
- Indemnity is supposed to cover the loss (basis risk)
- Premium not to expensive (government grant)

Insurance marketer: *increasing sales*

- Appropriate distribution channel
- Basis risk management

Index provider: *making profit*

- Proving index performance

1.4. Indirect Stakeholders Expectations

Agricultural trade association: *servicing farmers*
- New product in a given political context

Regulatory body: *solvency rules*
- Index knowledge (data, basis risk)

State: *controlling cost & volatility*
- Index knowledge (data)
- Challenging *National agricultural risk management fund*

Reinsurance company: *making profit*
- Index knowledge (data)
- Risk financing (investors)

Investors: *portfolio management*
- Index as an asset class (data frequency)

According to Jensen (2002):

$$\mathrm{Max}\, earnings \text{ u.c. } \begin{cases} basis\ risk \le threshold_{br} \\ index\ knowledge \ge threshold_{ik} \\ asset\ class\ identified \end{cases}$$

2. Insurance Indexes in Agriculture
2.1. Indices

INDEX TYPE

Area yield index

Weather index

- Rainfall, temperature

Remote-sensing index

- Evapotranspiration
- Vegetation
  - NDVI
  - fCover

PROVIDERS

Insurers

Weather stations network owners

Private satellite owners

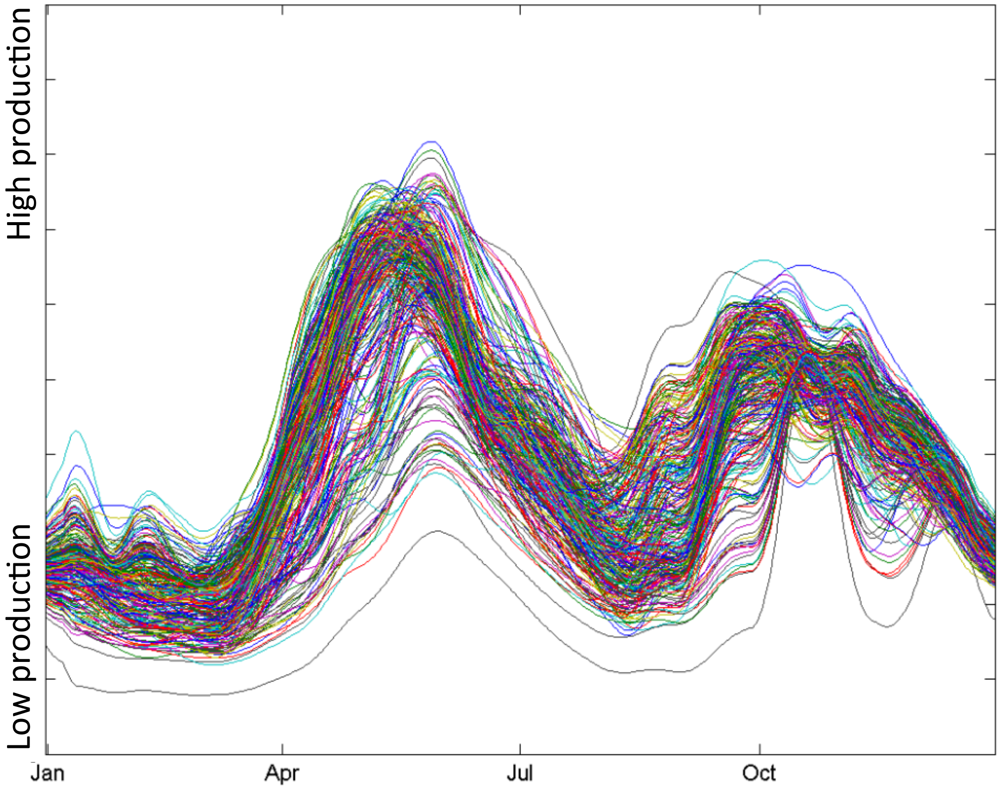
2.2. Indices & Stakeholders Expectations

Criteria	Area yield index	Weather index	EVP	NDVI	fCove
' to assess the risk:					
Accurate and reliable, not subject to revisions			x		x
Long historical data available			x	x	x
Time consistency	x	x	x		x
ervable, quantifiable and clearly defined	x	x	x	x	x
ely available		x	x	x	x
pendant and credible provider		x	x	x	x

3. Insurance Index Case & Sensitivity
3.1. Index Presentation

Example of the index behavior over the year:

→ index describing forage production



3.2. Sensitivity to Market

Capital Asset Pricing Model: $\mathbb{E}(R_{index})=R_f+\beta_{index}(\mathbb{E}(R_m)-R_f)$

Where:

- $\mathbb{E}(R_{index})$ is the expected insurance index return
- $\mathbb{E}(R_m)$ is the expected market return
- R_f is the « risk-free » interest rate

	β_{index}	p-value	Correlation coefficient
Eurostoxx 50	0.50	0.63	0.05
CAC 40	0.49	0.65	0.05

- **These results underline the diversifying « power » of the insurance index**

4. Perspectives

Agricultural Insurance Index as an Asset Class:

- Improving index performance for all stakeholders
- Non-idiosyncratic risk pricing
- Agricultural Insurance-linked securities

Farmer Financial Protection Schemes :

- Increasing agricultural insurance capacity
- National protection scheme, involving the insurance industry, the State & investors.

Thanks for your attention !

References

Barry, Peter J., Steven T. Sonka, and Kaouthar Lajili, 1992, "Vertical Coordination, Financial Structure, and the Changing Theory of the Firm," *American Journal of Agricultural Economics* 74: 1219-1225.

Jensen, Michael C., 2002, "Value Maximization, Stakeholder Theory, and the Corporate Objective Function", *Business Ethics Quarterly*, 12 (2), 235-256.

Just, Richard E., and Linda Calvin, 1993, "Moral Hazard in U.S. Crop Insurance: An Empirical Investigation." Unpublished manuscript. College Park: University of Maryland, College of Agriculture and Natural Resources.

Swiss Re, 2009, "The role of indices in transferring insurance risks to the capital markets", Sigma n°4/2009.

Calibrating a Satellite-based forage index with actual farmer losses in the Dominican Republic

A collection of thoughts… and some preliminary results

Thomas Barré
I4 – Index Insurance Innovation Initiative
University of California, Davis

Global Index Insurance Workshop
September 16^{th}, 2015

A little bit of contextualization

- USAID – Climate Resilience and Index Insurance program in the Dominican Republic
  - Focuses on dairy farmers in the Northwest of the country
  - In 2011, a prolonged drought killed 3,000 cows in the region.
  - Since then, every year is "extraordinarily" bad
  - The CRII program started in 2013 and promotes
    - risk mitigation measures (wells, irrigation, drought resistant plants, etc.)
    - Satellite-based index insurance tracking pasture conditions

- Our initial role in this program: evaluate the impact of the index insurance component of the program

- Our new role: improve the insurance contract design to increase its value for the farmers

Risk in dairy farming

- Dairy farmers are exposed to several types of risk:
  - Stolen cows
  - Accidental death
  - Diseases
  - Weather related r slide, etc.):
    - Dead cows
    - Reduced milk production
    - Low quality milk (lower price)
    - Increase in expenses (food and water)

Assets, Revenue & Costs

A calibration issue

- Losing cows is very expensive.
- Production costs could explode before we see a significant drop in milk production
- Even an area-yield index on milk production data is probably not enough.
- We want to capture costs as well
- But there is no data on costs of production.

Innovations in Index Insurance for dairy farmers

- Profit index insurance
- Remote sensing
- Quality measures and selection of the best index
- Risk pricing with short/breaking data

Innovations in Index Insurance for dairy farmers

- **Profit index insurance**
- Remote sensing
- Quality measures and selection of the best index
- Risk pricing with short/breaking data

Insuring profits

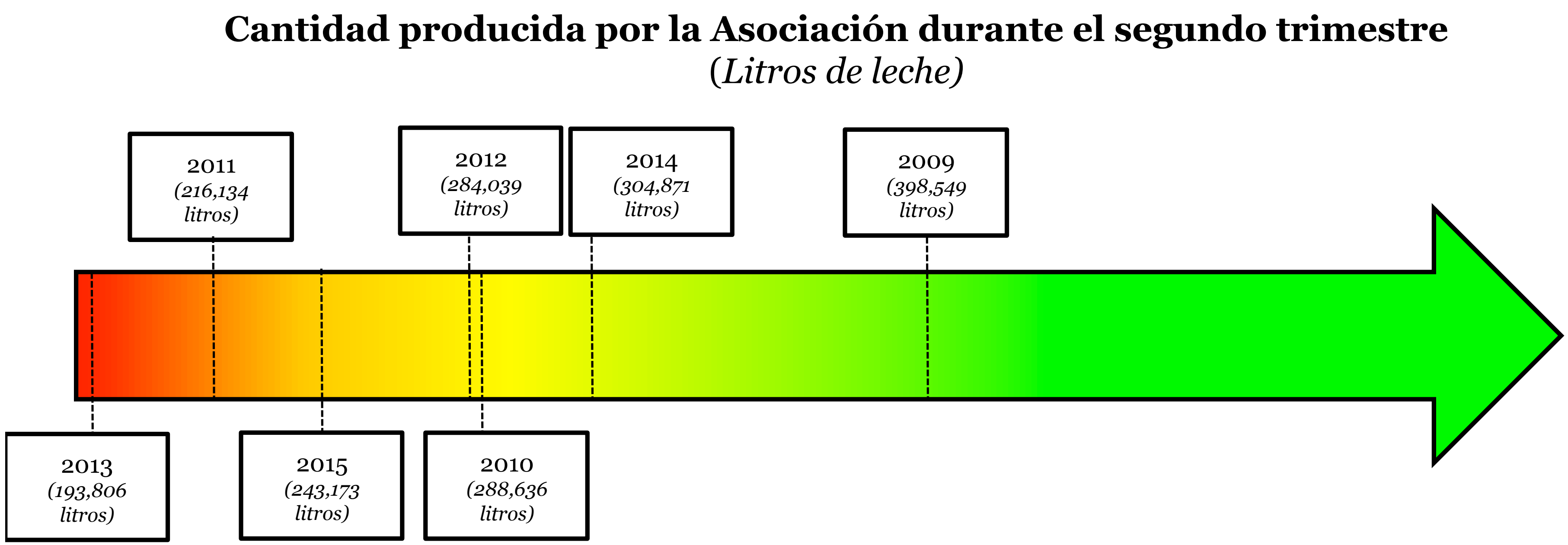
- In the Dominican Republic, farmers are organized in associations and milk production and price data are recorded daily.
- But no data on costs of production.
- Could use remote sensing data to proxy costs of production:

$$\pi_{i,v,t} = p_{v,t} \, . \, q_{i,v,t} - C(index_{v,t})$$

- But individual production data mostly on paper…

If we don't develop the collection of production data, we try to capture everything with a single remote sensing index…

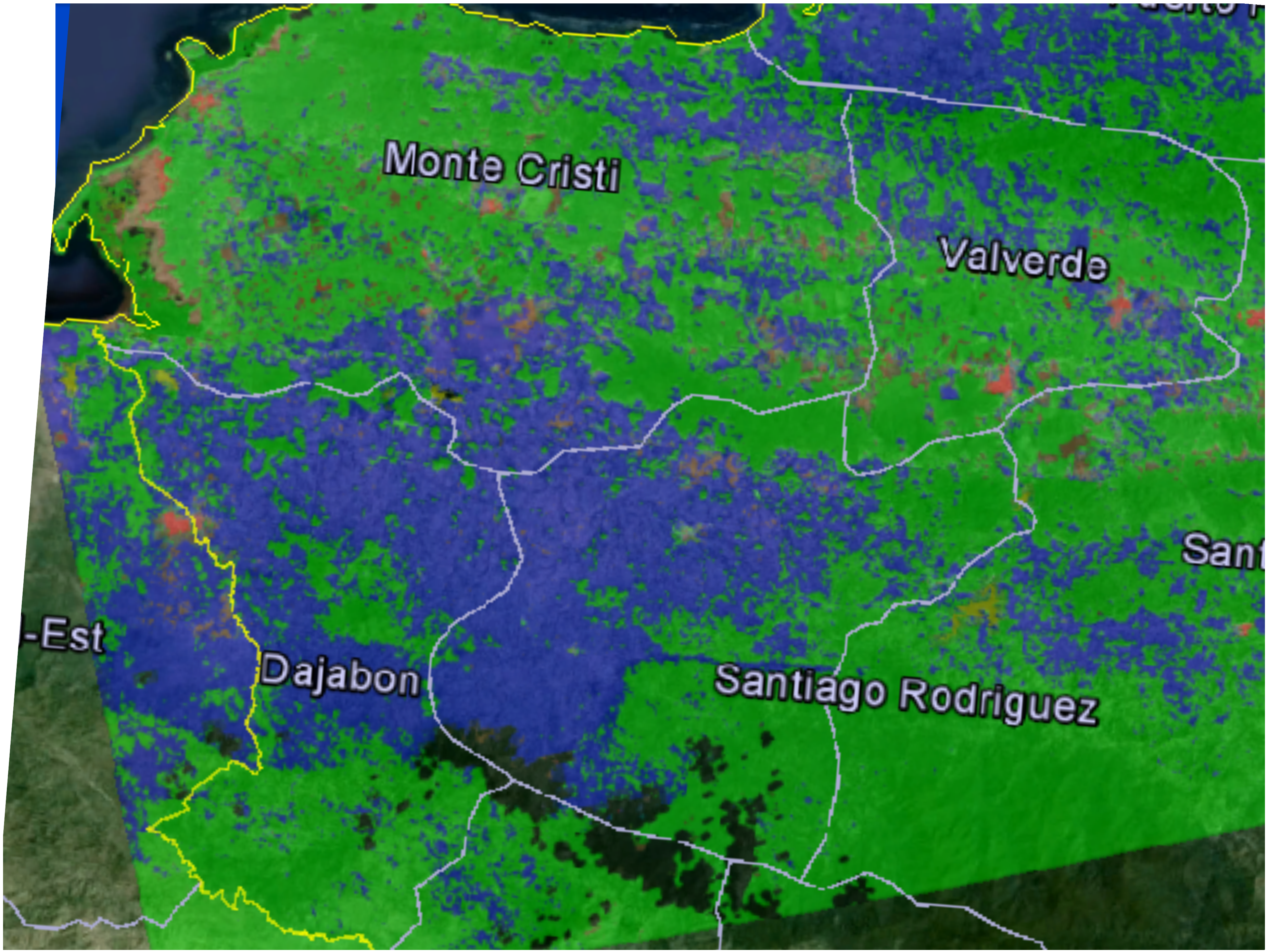
What about association-level milk data?



- 2013 appears as the worst year.
- The true story is that several farmers left the association that year. 2011 was a much harder year for them

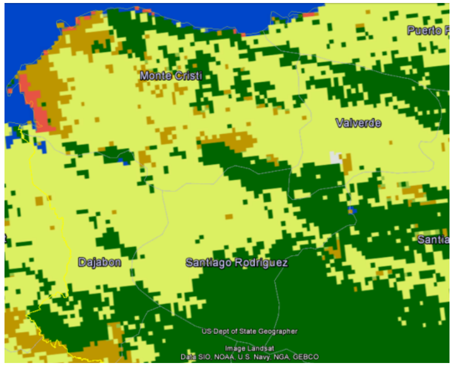
Innovations in Index Insurance for dairy farmers

- Profit index insurance
- **Remote sensing**
- Quality measures and selection of the best index
- Risk pricing with short/breaking data

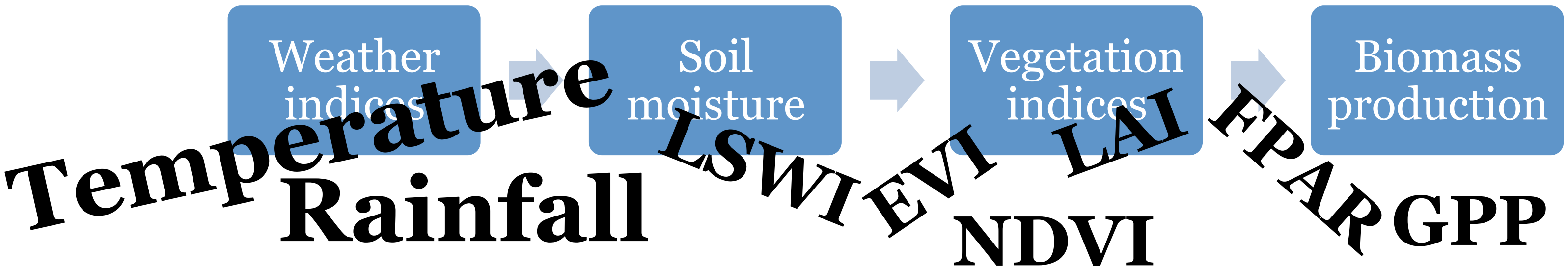

Monte Cristi
Valverde
Dajabon
Santiago Rodriguez
-Est
Sant

Using remote sensing

- Importance of good crop masking models



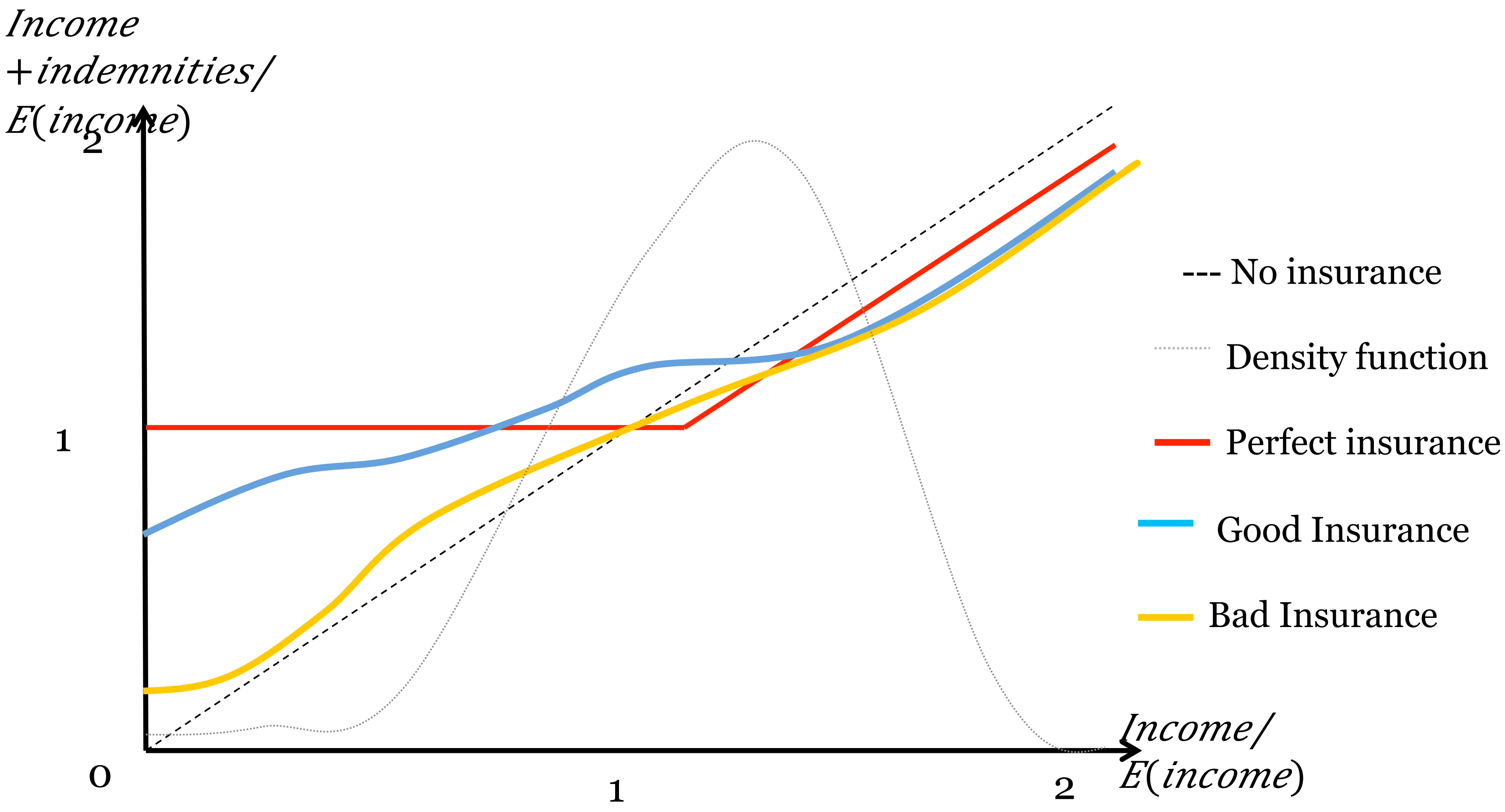
- Several potential Remote sensing indices



Innovations in Index Insurance for dairy farmers

- Profit index insurance
- Remote sensing
- **Quality measures and selection of the best index**
- Risk pricing with short/breaking data

Insurance Quality measures

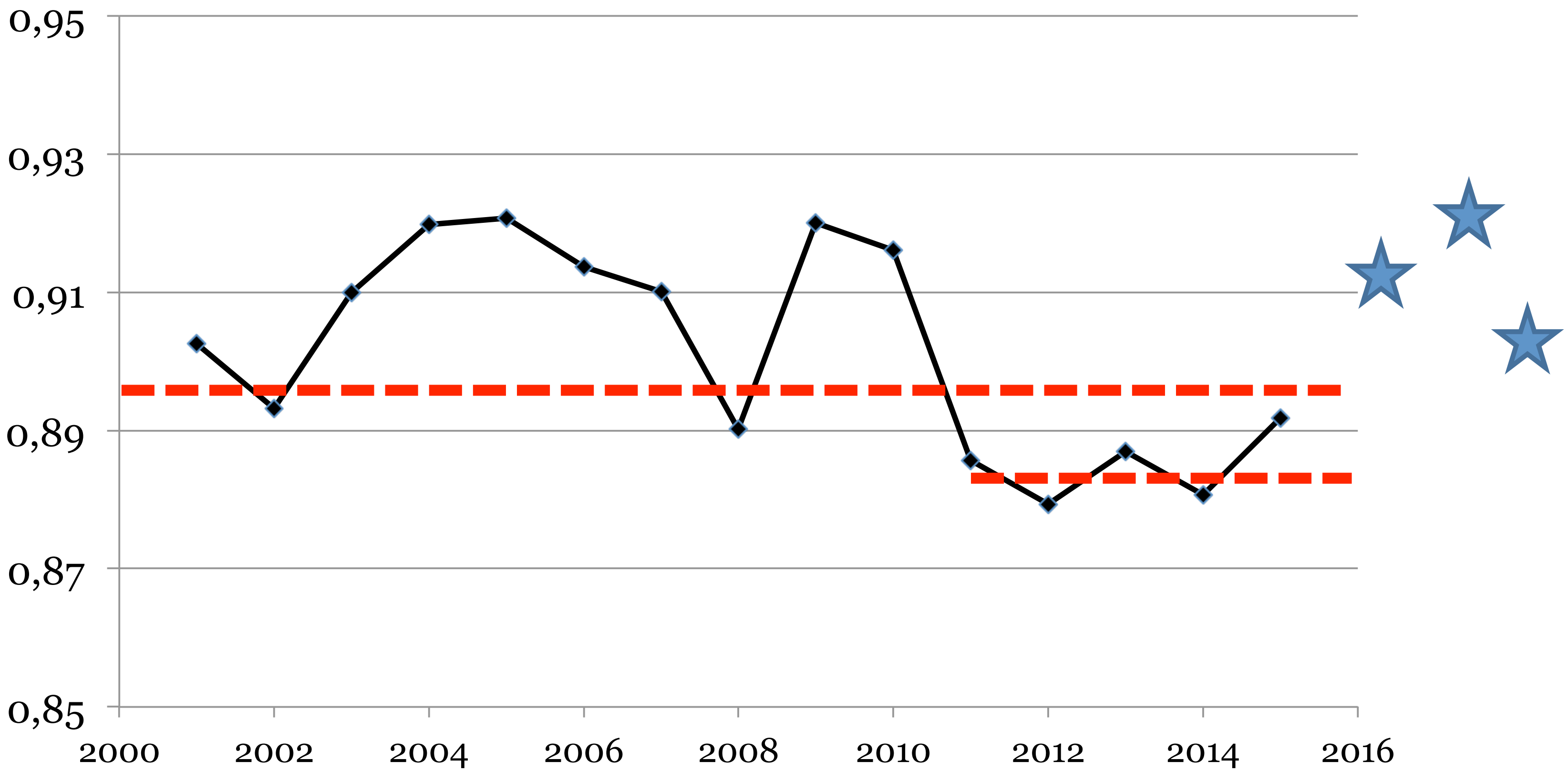


Innovations in Index Insurance for dairy farmers

- Profit index insurance
- Remote sensing
- Quality measures and selection of the best index
- **Risk pricing with short/breaking data**

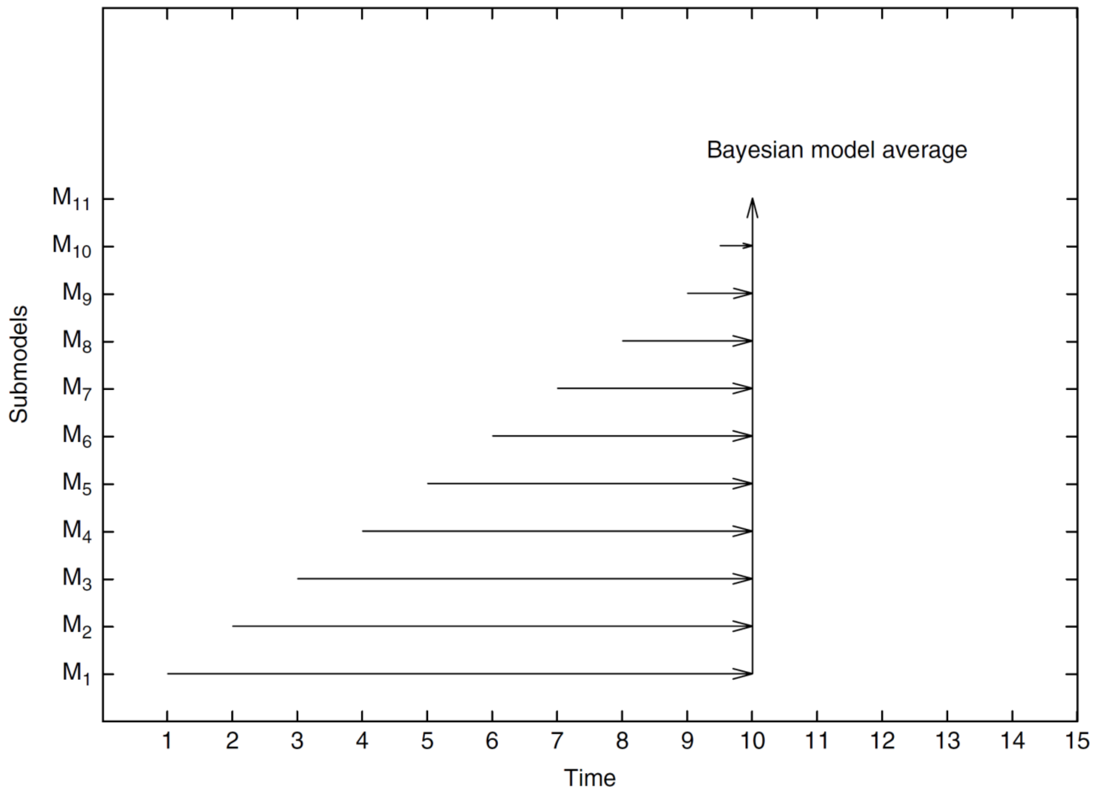
Risk pricing with short/breaking time series

- NDVI values in recent years



Modern techniques in risk pricing

- Maheu & Gordon (JAE 2008)



- We have 11 years of data.
- We estimate 10 models with the data from t1 to t10.
- Compute weights based on the ability of each model to predict the data for t11.
- These weights are then used to predict the distribution of yields in t12.


Thanks!

Is Combining Remote Sensing and Climatic Data Interesting to Estimate Grassland Production ?

Antoine Roumiguié, PhD student

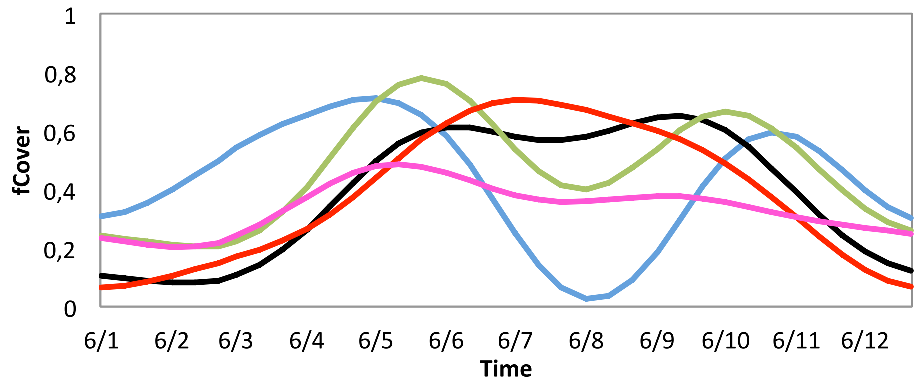
antoine.roumiguie@purpan.fr

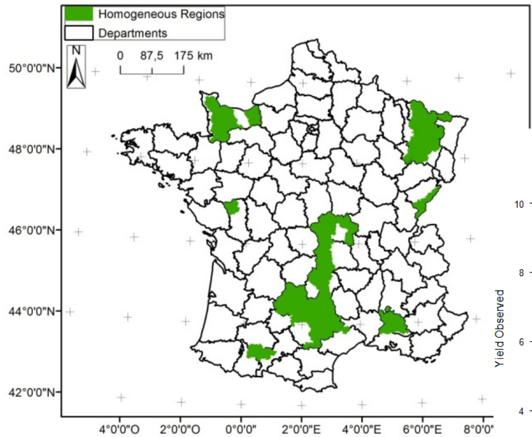
Anne Jacquin, PhD

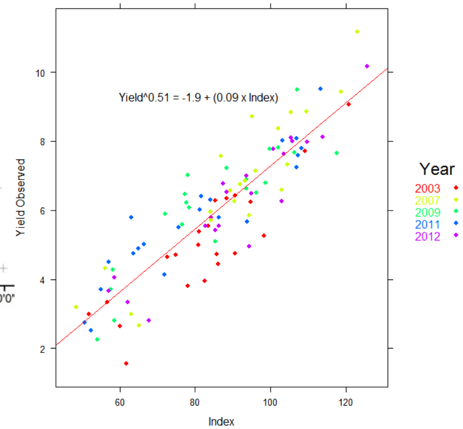
anne.jacquin@purpan.fr

Université de Toulouse, INP Toulouse – Ecole d'Ingénieurs de Purpan, UMR 1201 DYNAFOR INRA

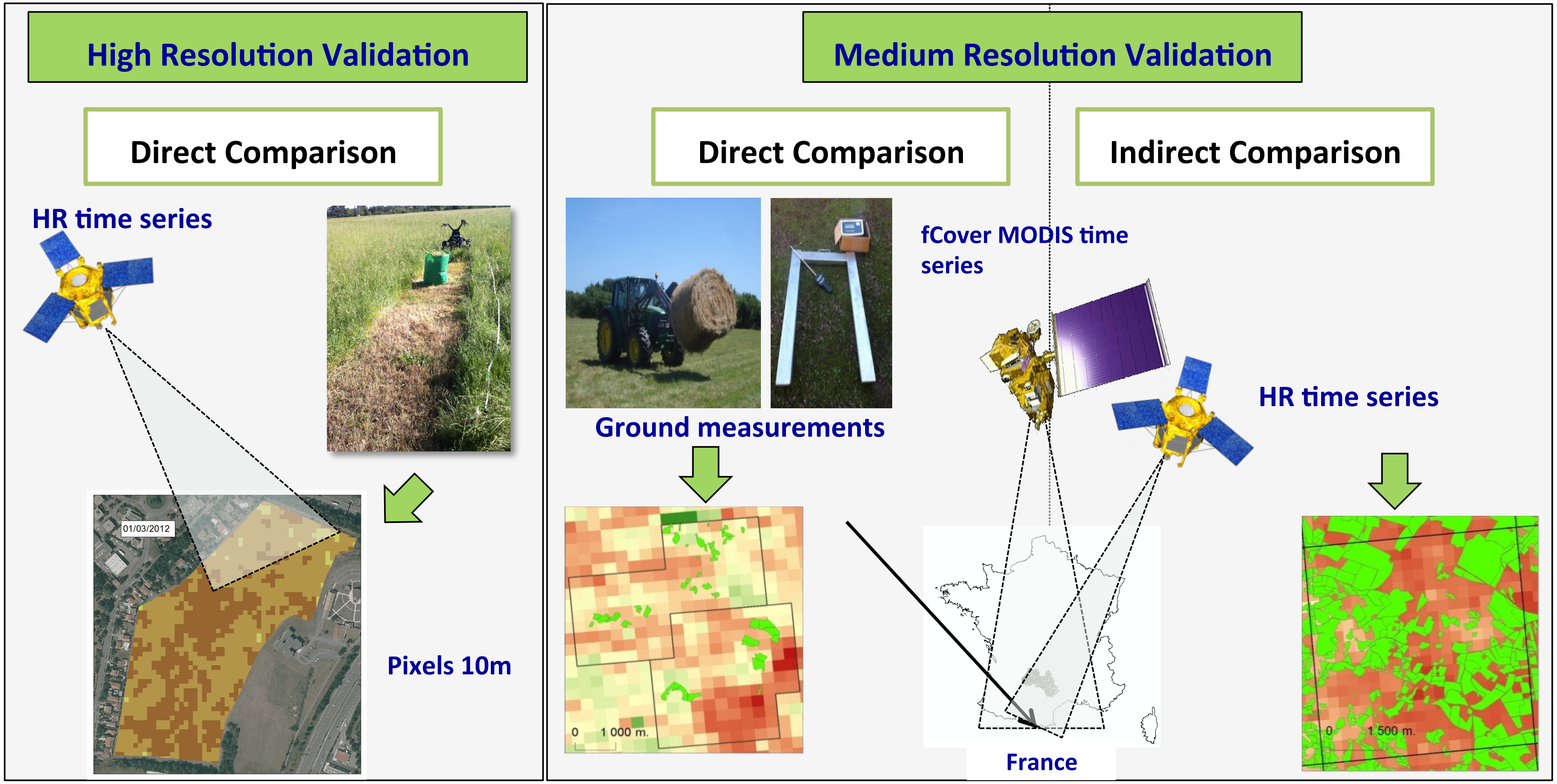
16/09/2015







My previous work on index-based insurance as a PhD student…

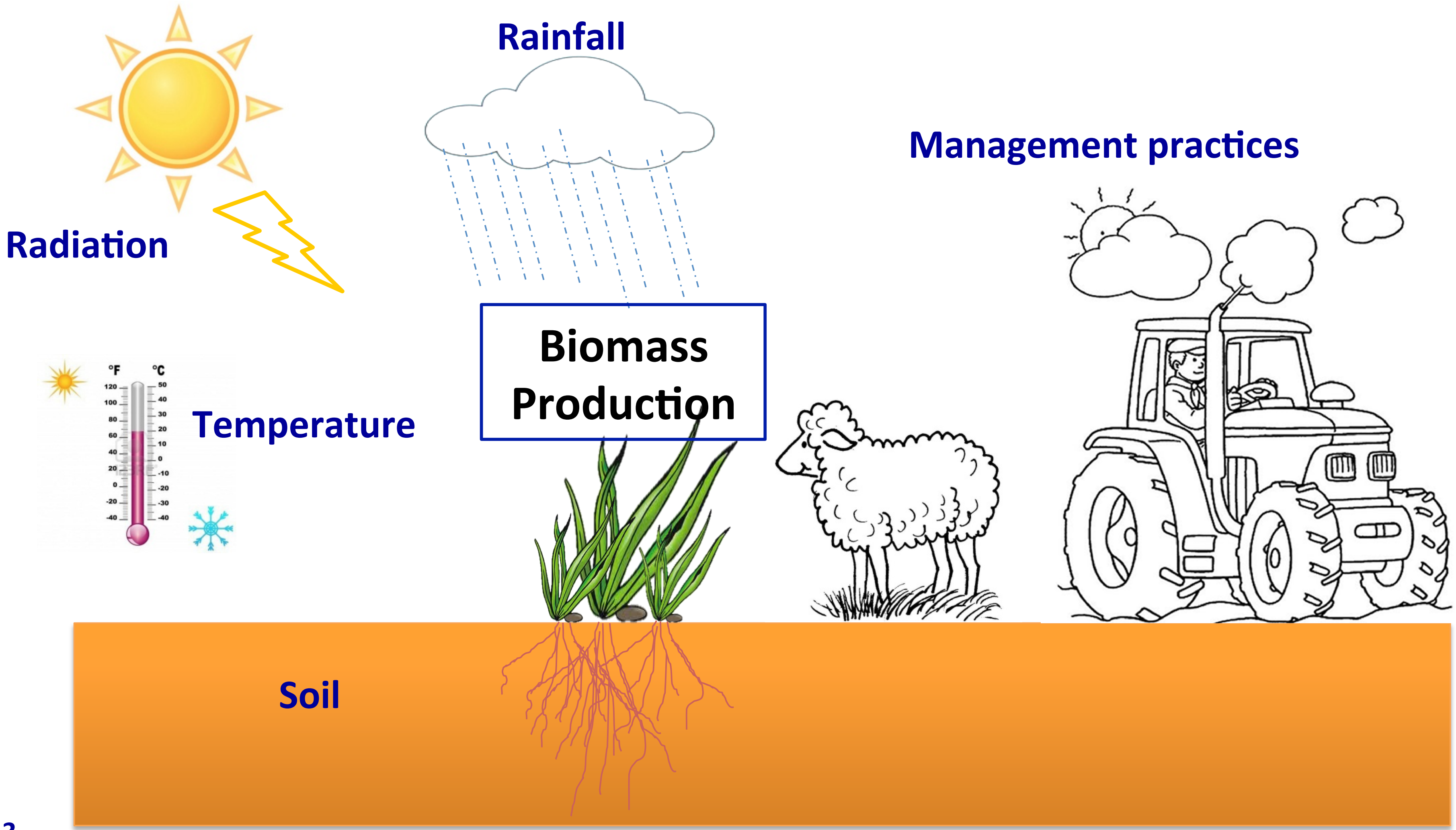


Roumiguie, A.; Jacquin, A.; Sigel, G.; Poilve, H.; Lepoivre, B.; Hagolle, O. **Development of an index-based insurance product: Validation of a forage production index derived from medium spatial resolution fcover time series.** GIScience & Remote Sensing **2015**, 52, 94-113.

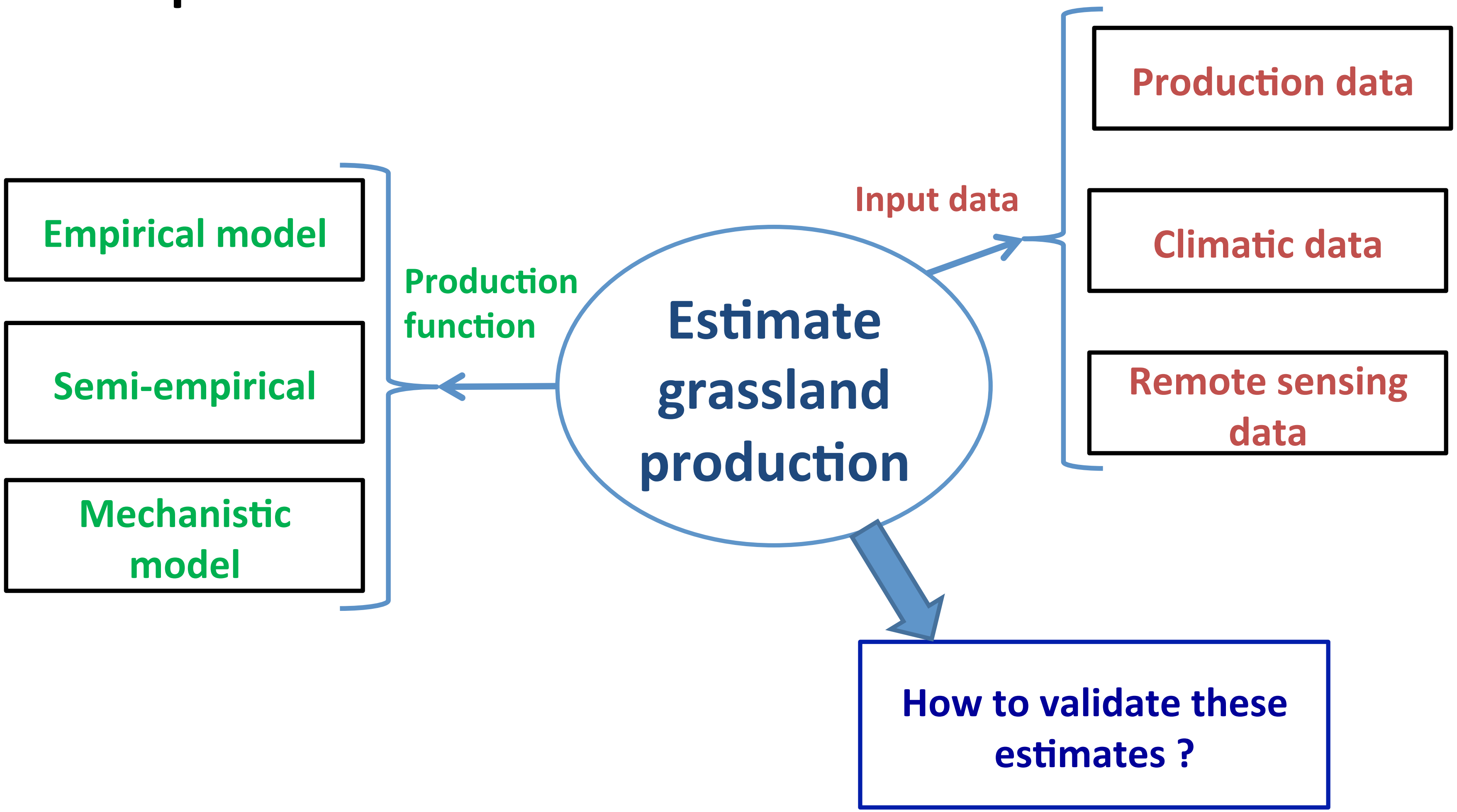
Roumiguié, A.; Jacquin, A.; Sigel, G.; Poilvé, H.; Hagolle, O.; Daydé, J. **Validation of a forage production index (FPI) derived from MODIS fCover time-series using high-resolution satellite imagery: Methodology, results and opportunities.** Remote Sensing **2015**, 7, 11525.

What are the driving factors of grassland production?

Edaphic conditions (soil, topography); Management practices (grazing/cutting); climatic variables : temperature, rainfall, radiation



Many methodological options to estimate grassland production depend on spatial and temporal resolution of the output data.



Existing agricultural insurance models for grassland production

	Index	Geographical scale of the estimation	Methodology	Input data source
Spain Agroseguro	NDVI	County (*Comarcas*)	**Empirical model** Comparison of historical and actual monthly NDVI values	MODIS @ 250 km
Mexico Agroasemex	NDVI	Farm reference	**Empirical model** Annual sum of NDVI of previous year integrating livestock data	NOAA-AVHRR @ 1.1 km
USA	NDVI	County	**Empirical model** Comparison of historical and actual NDVI 3 months values	USG-EROS @ 8 km
USA	Rainfall	Grid of 27 km	**Empirical model** Comparison of the sum of daily rainfall over 2 months with the historical values	NOAA CPC
Canada Alberta	NDVI	County	**Empirical model** Comparison of historical and actual NDVI weekly values	NOAA-AVHRR @ 1.1 km
Canada Ontario	Rainfall	Weather station distribution	**Empirical model** Comparison of historical and actual sum of rainfall over the growing season	Weather station
France	fCover	County (*Commune*)	**Empirical model** Comparison of historical and actual sum of daily fCover between 1st February and 31 October.	MODIS @ 250m/ MERIS @ 300m
France		Forage Region	**Mechanistic model**	Climatic data Pedologic data Field survey

Empirical models with NDVI are easier to compute, thus predominant
BUT, mechanistic models are leading to better production estimates at a local scale.

In the *French* case, is it interesting to evolve from an empirical model to a semi-empirical model? Different options are tested.

What could be a semi-empirical model?

Data:

- Remote sensing data: **Biophysical parameter** (fCover or fAPAR) or **Vegetation index** (NDVI)
- Climatic data: **Radiation**, **Temperature**, **Rainfall**

Monitoring period : Fixed or **Variable** according to the remote sensing index profile.

Grassland production estimating method: Sum of the daily production function

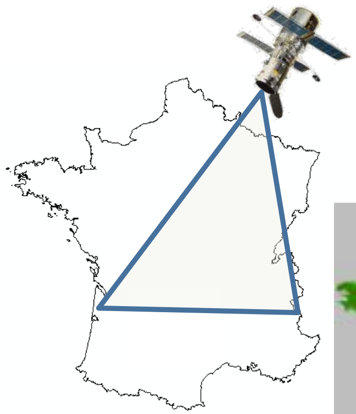
Objectives:

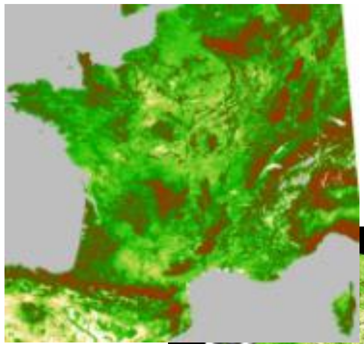
1) **Choose the best remote sensing index**
2) **Assess the importance of monitoring period**
3) **Define the best production function**

Objective 1: Choose the best remote sensing index

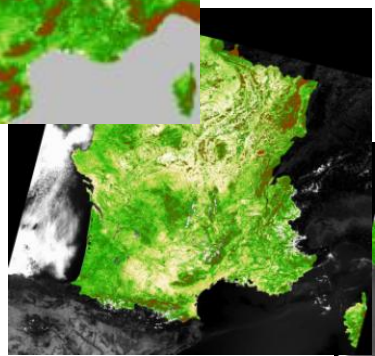
Options tested : NDVI / fAPAR / fCover ?

Vegetation monitoring with remote sensing images

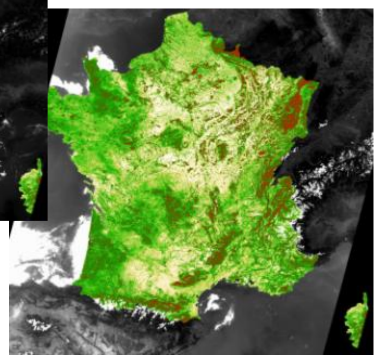




NDVI



fAPAR*



fCover*

NDVI => MODIS Sensor; MOD13Q1 product :
- 250 m Spatial resolution
- 16-day images

fAPAR/fCover => MODIS/MERIS Sensors:
- 300 m Spatial resolution
- 10-day images

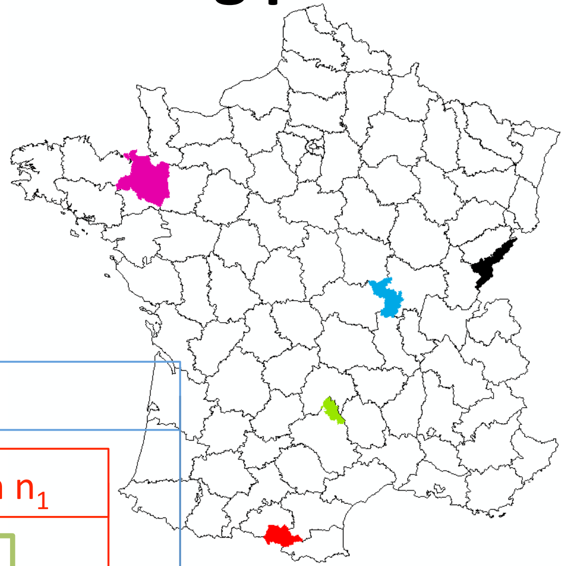
Spectral desagregation to focus exclusively on **grassland landcover**
6 km x 6 km

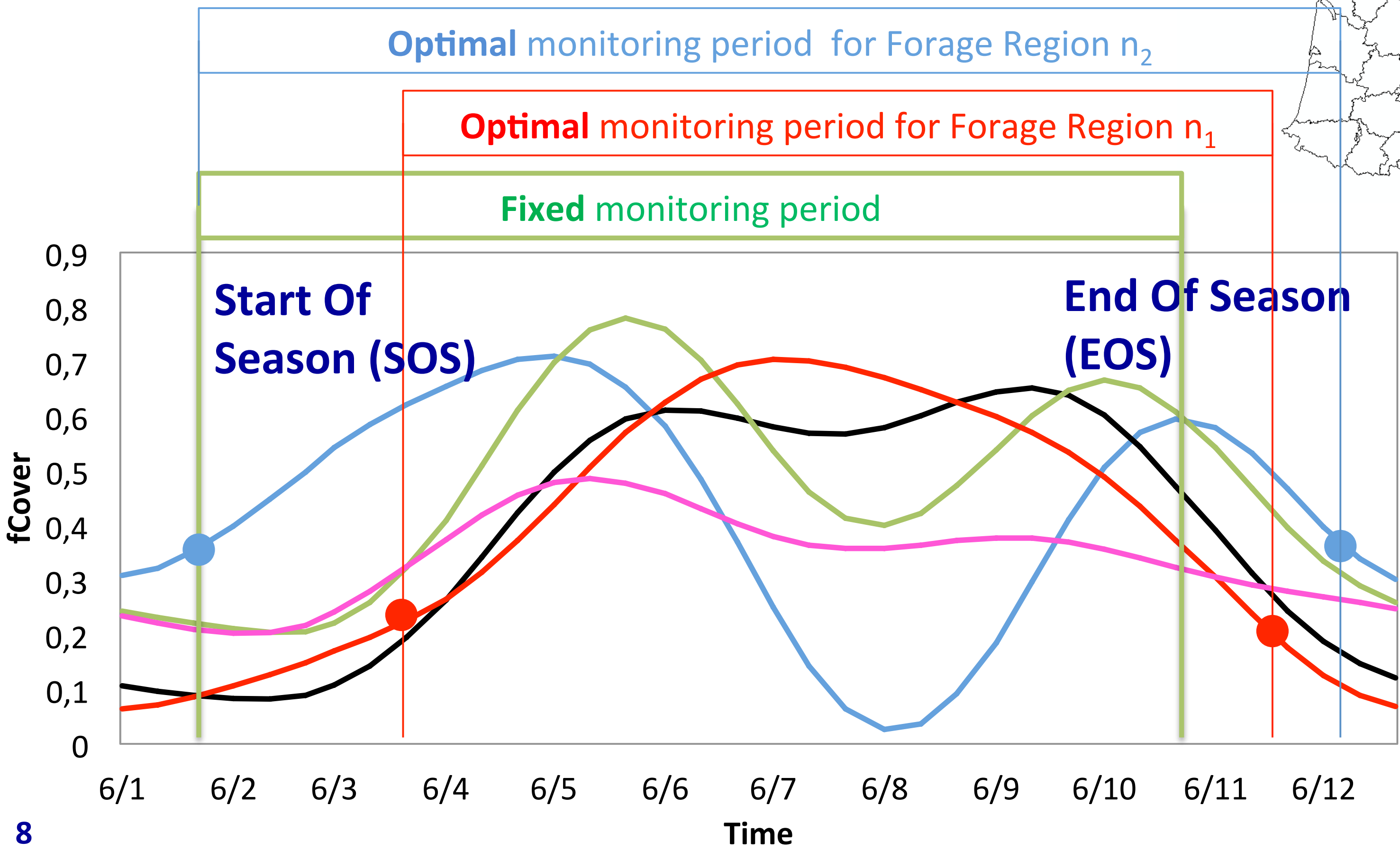
Spatial Aggregation according **to validation dataset**
Administrative (county, department) or pedoclimatic units (forage region)

*fAPAR/fCover from daily reflectance images of MODIS (MOD02HKM / MOD02QKM - 250m spatial resolution) and MERIS (300m spatial resolution) sensors – Obtained by biophysical inversion

Objective 2: Assess the importance of monitoring period

Option 2 : Fixed or variable monitoring period?





Objective 3: Define the best production function

Option 3: Additional climatic variables (radiation, temperature, rainfall) in biomass production function

Taking into account physiological effects…

- **Radiation** (Monteith and Moss 1977)
- **Temperature effect on photosynthesis efficiency** (Duru et al. 2010)
- **Seasonality effect on photosynthesis** (Cros et al. 2003)
- **Phenological effect on photosynthesis** (Duru et al. 2010)
- **Water Stress effect** (Maselli et al. 2013)
- **Senescent function** (Duru et al. 2010)
- **Considering one or multiple growing season for the year** (Duru et al. 2010)

Monteith, J.L.; Moss, C.J. Climate and the efficiency of crop production in britain [and discussion]. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* 1977, *281*, 277-294.
Duru, M.; Cruz, P.; Martin, G.; Theau, J.P.; Charron, M.H.; Desange, M.; Jouany, C.; Zerourou, A. Herb'sim, a model for a rational management of grass production and grass utilization. *Fourrages* 2010, 37-46.
Cros, M.J.; Duru, M.; Garcia, F.; Martin-Clouaire, R. A biophysical dairy farm model to evaluate rotational grazing management strategies. *Agronomie* 2003, *23*, 105-122.
Maselli, F.; Argenti, G.; Chiesi, M.; Angeli, L.; Papale, D. Simulation of grassland productivity by the combination of ground and satellite data. *Agriculture, Ecosystems & Environment* 2013, *165*, 163-172.

Calibration/validation datasets

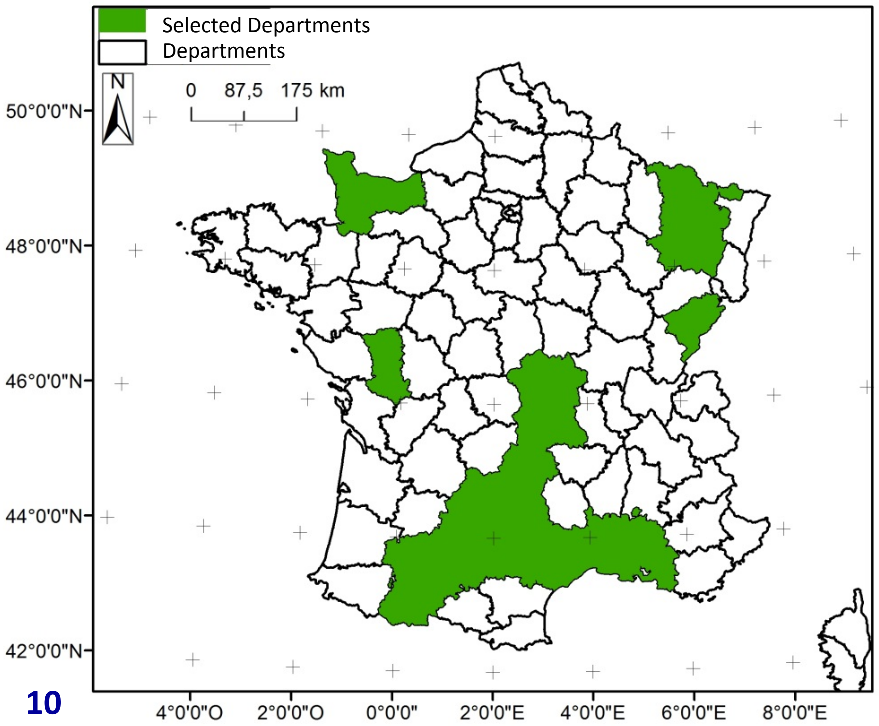
Selection of 5 representative years:

2003,2011 for dry conditions; 2009,2012 for normal and 2007 for wet conditions

… and zones of interest.

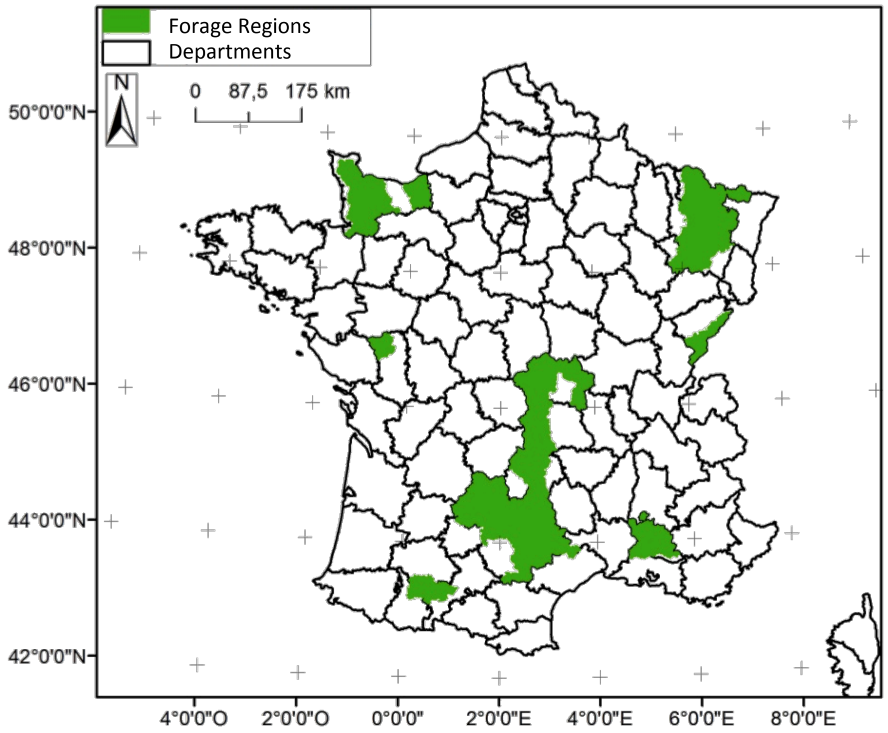
21 Departments (administrative units)

=> 105 points *Yield observation* *(source: Agreste)*



25 Forage Regions (pedoclimatic units)

=> 125 points *Yield observation* *(source: ISOP)*



A methodology is defined to compare each model.

"Base" Model:

Empirical model with remote sensing data (fCover)

$$Yield = a \times Index + b + \varepsilon$$

Developed Models:

Semi-empirical models with remote sensing and climatic data

Calibration and **validation** (3-Folds Cross Validation)

Base Model:
$NRMSE_{Base}$

Developed Models:
NRMSE

$$NRMSE = RMSE / Mean(Yield)$$

Models **classification**

- **errors modeling** (NRMSE)
- **residuals validity** (Homoscedasticity and Normality)

Selection of models with a **higher performance** than the « Base » model

Overall results

1728 Developed models tested with calibration/validation dataset

"Base" Model :

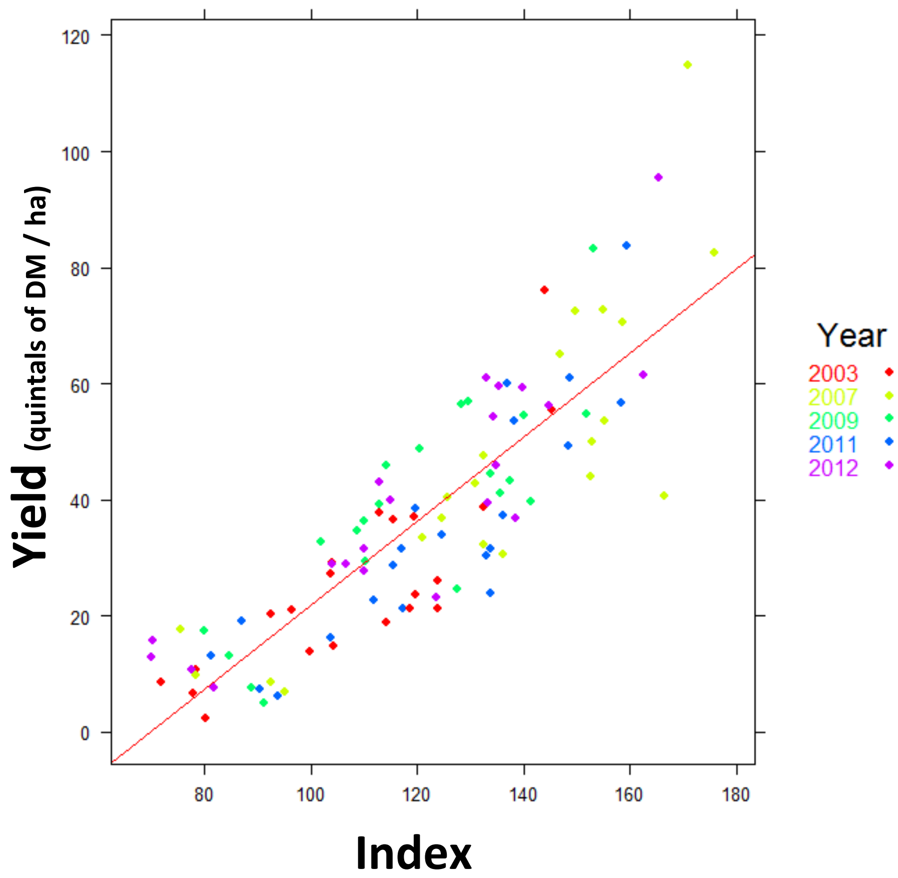
Performance level

- $NRMSE_{Base} = 13.2\ \%$
- $R^2_{Base} = 0.738$

158 models outperform the "Base" model

$NRMSE_{Base}$ maximum increase **= 14%**

Mean increase = 6 %



Among new models, few are outperforming the "Base" model.

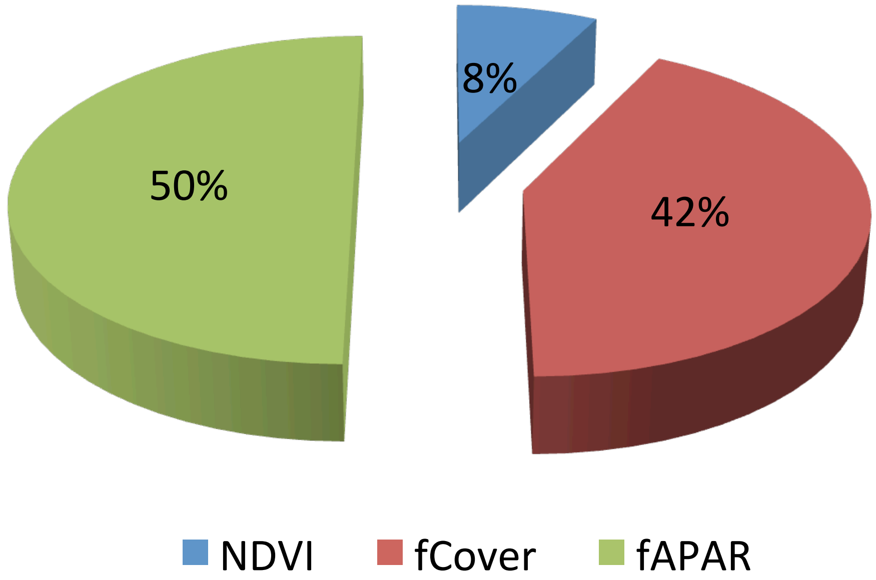
Results concerning the best index to use…

“Base” Model :

Level of performance

- $NRMSE_{Base}$ = 13.2 %
- R^2_{Base} = 0.738

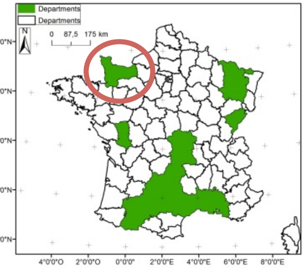
Remote sensing index frequency among the 158 models :



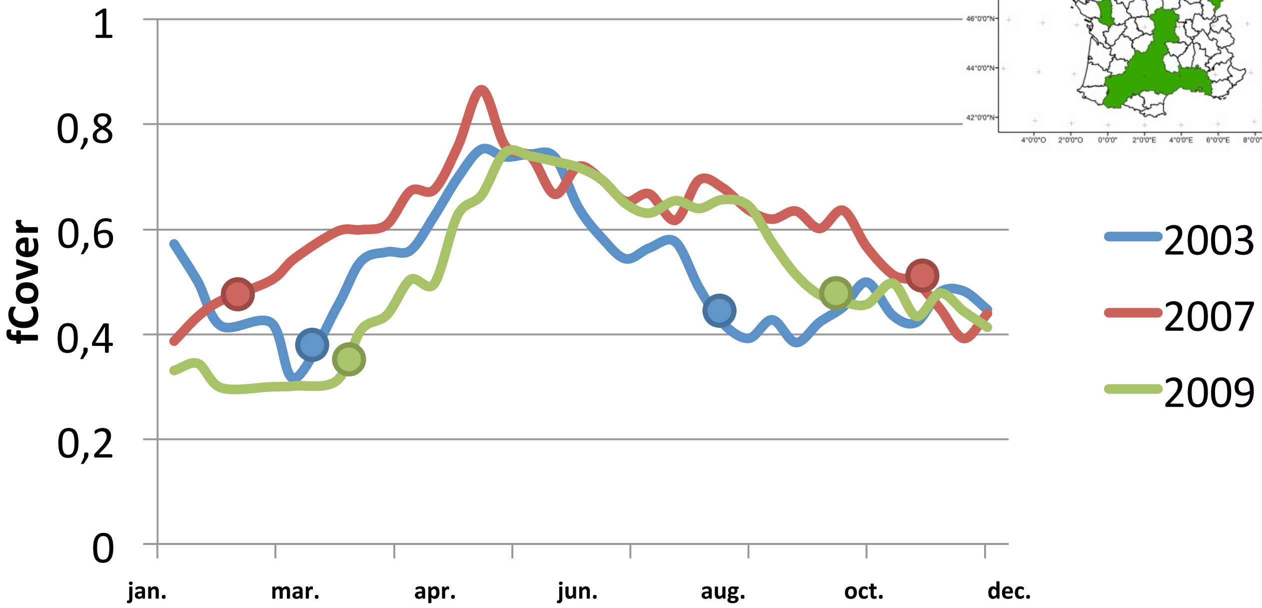
	NDVI	fCover	fAPAR
NRMSE (%)	**13.1**	**11.4**	**11.9**

fAPAR and fCover are the best candidates for biomass estimating.

Results concerning the monitoring period…



Examples of the variation between SOS and EOS for a department (Calvados) and for 3 distinct years



For the 158 models, the monitoring period is:

- **variable** for 51 %,
- **fixed** for 49%.

The interest of integrating a variable monitoring period is not obvious. Further analysis are required.

Results concerning the best production function…

Physiological Effects	Frequency among the 158 models
Radiation	60 %
Temperature effect on photosynthesis efficiency	69 %
Seasonality effect on photosynthesis	56 %
Phenological effect on photosynthesis	74 %
Water Stress effect	78 %
Senescent function	0%
Considering one or multiple growing season for the year	92 % with one season only

Consequences for the production function :

- 3 physiological effects are interesting,
- 2 physiological effects lead to non obvious conclusions,
- 2 physiological effects are not relevant.

Conclusions concerning a semi-empirical model to estimate grassland biomass production

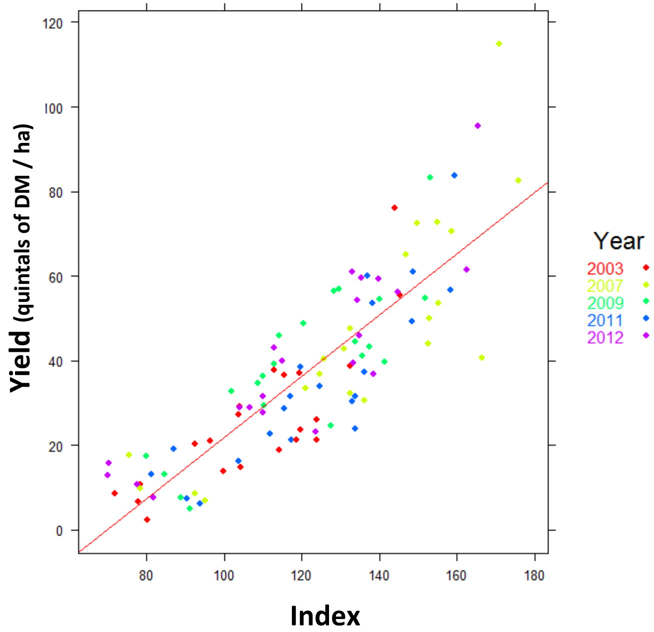
- **Objective 1**: Best Index **=> fAPAR** (or fCover)

- **Objective 2**: Monitoring period **=> Variable** (to be confirmed)

- **Objective 3**: Production function **=>** Additional climatic variable , **radiation / temperature / rainfall** to consider 3 physiological effects :
  - **Temperature effect on photosynthesis efficiency**
  - **Phenological effect on photosynthesis**
  - **Water Stress effect**

Summary…

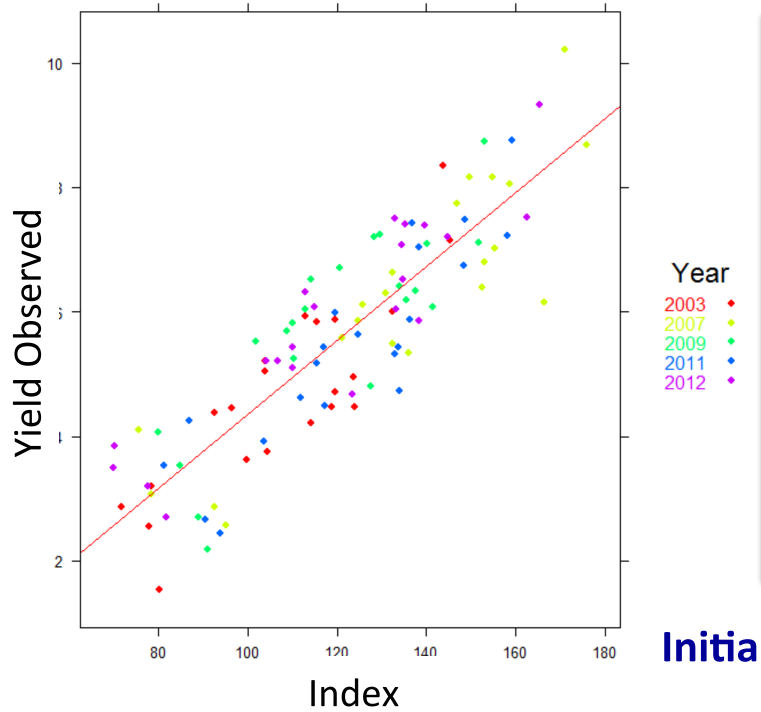
- **The actual empirical model used for grassland insurance in France gives satisfactory estimates of biomass production.**
- **A semi-empirical model combining climatic and remote sensing data provides improvement in grassland production estimation.**
- **For the development of a commercial insurance product, a cost/benefit analysis of adding climatic data in the production function needs to be performed.**



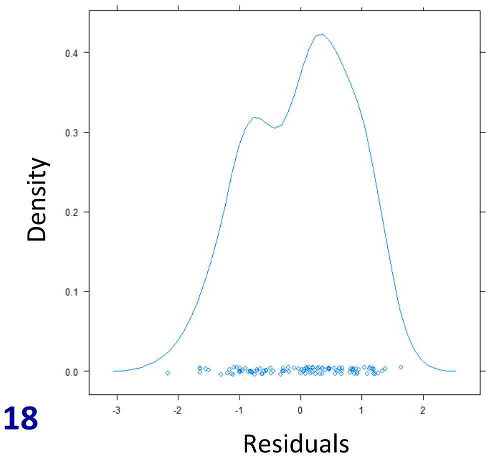
Questions?

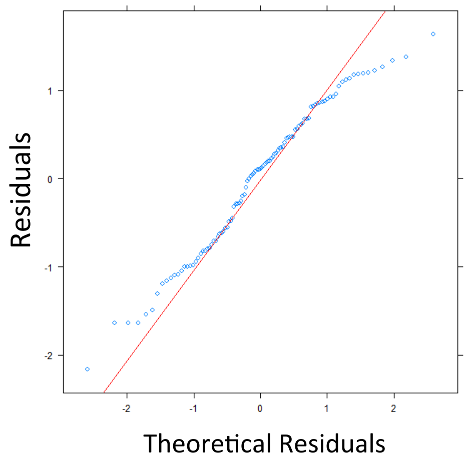
antoine.roumiguie@purpan.fr
anne.jacquin@purpan.fr

Conclusions concerning a semi-empirical model to monitor grassland biomass production

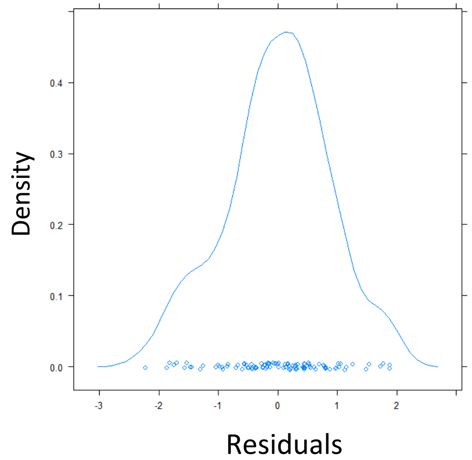


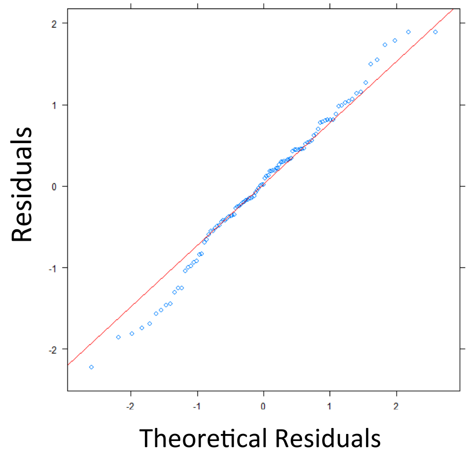
Initial model

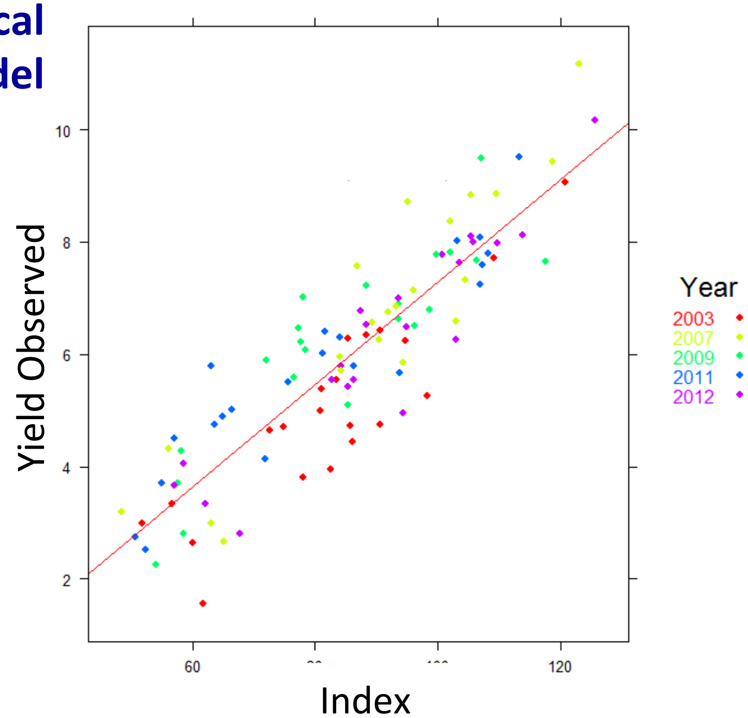




Semi-empirical model







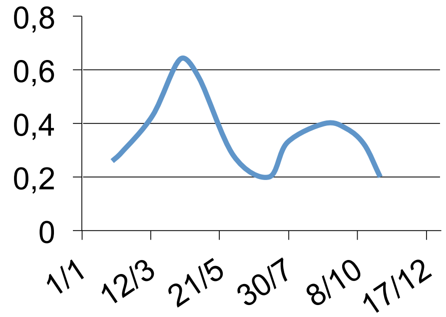
Different options are tested.

2) Daily climatic data

- *Temperature*
- *Radiation*
- *Rainfall*

SAFRAN Database (INRA, MeteoFrance)

1) Time Series of **Biophysical parameter** or **vegetation index**



$$Yield_{n,d} = \int_{SOS}^{EOS} (Rad_{n,d,i} \times RUE_{n,d,i} \times RS\ index_{n,d,i}) \times d_i$$

with,

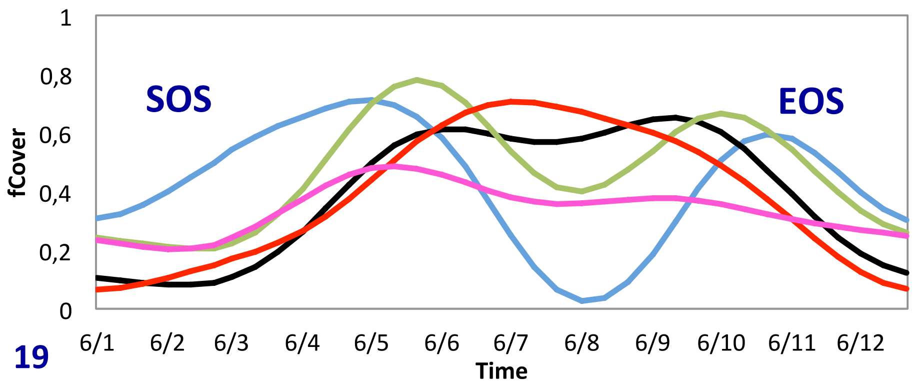
Index$_{n,d}$: Index for a Year *n* and a zone *d*

RUE$_{n,d,i}$: Radiation Use Efficiency for a day *i*

RS Index$_{n,d,i}$: Remote Sensing Index

Rad$_i$: Radiation for day *i*

3) Monitoring period



Calibration and validation with reference data

A methodology is defined to compare each model and identify the best development for the biomass estimation.

Initial Model:

$$\boldsymbol{Yield_{n,d}} = a_1 \times \int_{01/02}^{31/10} (\boldsymbol{fCover_{n,d,i}}) \times d_i + a_2 + \varepsilon_{n,d}$$

Developed Models:

$$\boldsymbol{Yield_{n,d}} = a_1 \times \boldsymbol{Yield\ sim_{n,d}} + a_2 + \varepsilon_{n,d}$$

Calibration and **validation** (3-Folds Cross Validation)

Initial Model: **RMSE**

Developed Models: **RMSE**

Models' **classification** according **errors estimate** (RMSE) and **residuals validity** (Homoscedasticity and Normality)

New model **improve** the biomass estimation

Preliminary results

1728 new models tested on both dataset

Initial Model:

$$Yield\ obs_{n,d} = a_1 \times \int_{01/02}^{31/10} (fCover_{n,d,i}) \times d_i + a$$

Departments

Objectives of quality are:

- $RMSE_T$ = 15.4 %
  (R^2_T = 0.762)

74 models **outperform** the initial version (after sorting on RMSE, R^2 and residuals)

Forage Regions

Objectives of quality are:

- $RMSE_T$ = 10.9 %
  (R^2_T = 0.713)

84 models **outperform** the initial version (after sorting on RMSE and residuals)

Among new models, few are outperforming the initial version.

Conclusions concerning the best index to use…

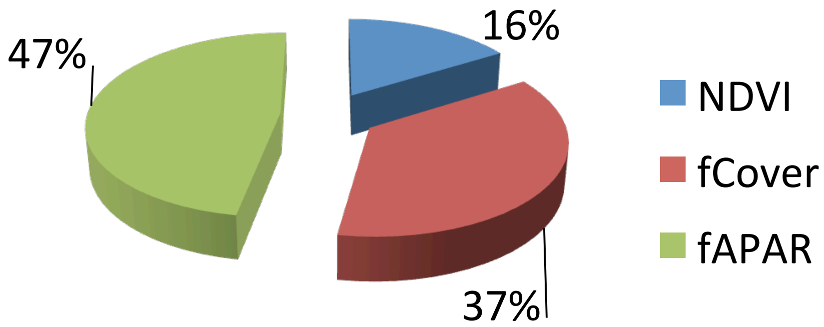
Departments

Objectives of quality are:

- $RMSE_T$ = 15.4 % (R^2_T = 0.762)

INDEX	RMSE	R^2	x
NDVI	0.118	0.806	0.41
fCover	0.133	0.750	0.41
fAPAR	0.134	0.754	0.41

Considering the best models :



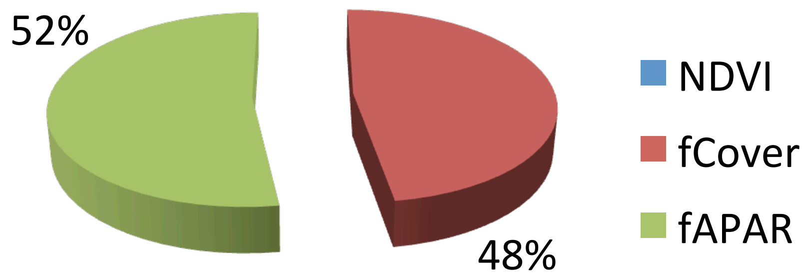
HP Regions

Objectives of quality are:

- $RMSE_T$ = 10.9 % (R^2_T = 0.713)

INDEX	RMSE	R^2	x
NDVI	0.143	0.710	0.52
fCover	0.096	0.750	0.38
fAPAR	0.103	0.752	0.40

Considering the best models :



fAPAR and fCover are the best candidates for estimating biomass.

Results concerning the monitoring period

Departments

For the 74 models,
30 (41 %) are computed with a **variable** window and
44 (59 %) are computed with a **fixed** window.

HP Regions

For the 84 models,
50 (60 %) are computed with a **variable** window and
34 (40 %) are computed with a **fixed** window.

The variation of the monitoring period has different consequence according to the calibration/validation dataset.

Results concerning the best production function…

Effects	Departments	Forage Regions
Radiation	51%	64%
Temperature effect on photosynthesis efficiency	50%	82%
Seasonality effect on photosynthesis	59%	50%
Phenological effect on photosynthesis	81%	64%
Water Stress effect	80%	73%
Senescent function	0%	0%
Considering one season or multiple growing season for the year	88%	92%

In the production function, some improvements are obvious while others depend of the calibration/validation dataset.

Processing Satellite Images to retrieve biophysical Information on Vegetation, application to Agriculture

Index Insurance Forum, Int. Research Workshop

Hervé Poilvé, Grégoire Sigel

Paris, 16 September 2015

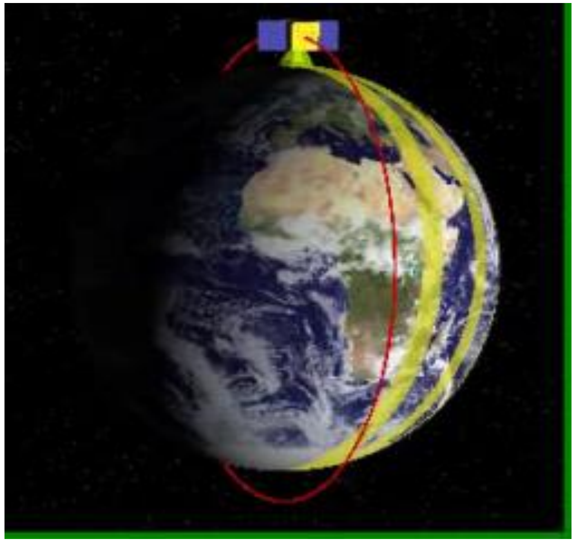
AIRBUS DEFENCE & SPACE

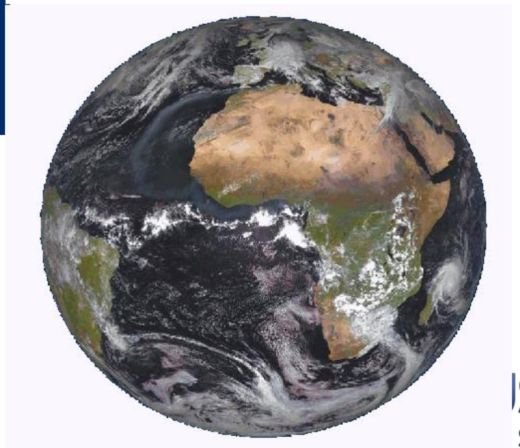
Earth Observation from Space – some key facts

Two major orbits: 'low Earth orbit' et geostationary

Low Earth orbit *(polar, Sun-synchronous..)*

- altitude 400 to 700 km
- resolution 1 km ⇨ < 1 m
- mapping, defence, thematic applications
- Landsat (1972 →), SPOT (1986 →), …
- optical and radar observation



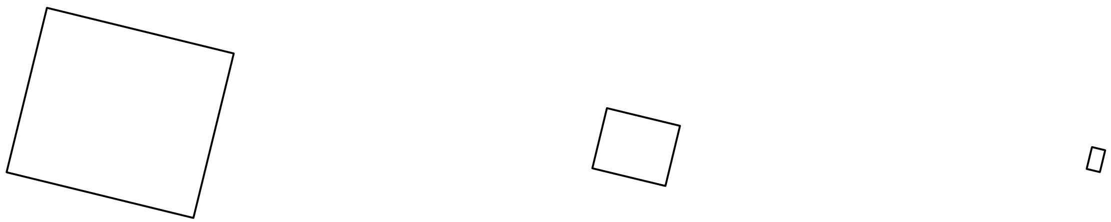


Geostationary

- altitude 36000 km
- resolution 7 km ⇨ 1 km
- major application : meteorology
- example : Meteosat (1977 →)

Optical satellites in low Earth orbit

- A large range of spatial resolution …
  - global imaging capacity varies accordingly



low resolution (LR) : 300 m -1 km
swath width 1200 to 2500 km
Earth coverage 1 to 2 days *

high resolution (HR): 5-30 m
swath width 60 to 650 km
Earth coverage 4 to 40 days *

very high resolution (VHR): 0.3 - 2 m
swath width 10 à 60 km
Earth coverage 40 to 240 days*

**** without considering clouds***

- Richness of information (spectral resolution)
  - in the Visible (Vis), Near Infra-Red (NIR) and Short-Wave Infra-Red (SWIR) domains
  - usually a minimum of 3-4 bands
  - 2 key bands to observe vegetation : Red/NIR
  - SWIR gives access to wetness information in vegetation volume
  - higher number of bands greatly improves accuracy and give access to new information (e.g. pigments)

AIRBUS DEFENCE & SPACE

Major EO missions for Agriculture

- Low Resolution (LR)
  - AVHRR *1.1 km – swath 2500 km – 4 bands VNIR-SWIR (+TIR)*
  - MODIS (Terra / Aqua) *250-500 m – swath 2500 km – 7 bands VNIR-SWIR (+TIR)*
  - VGT (Spot 4 † 2014 / Spot 5 † 2015 / Proba-V) *1 km – swath 2500 km – 4 bands VNIR-SWIR*
  - MERIS (Envisat † 2012) / Sentinel-3 : *300 m – swath 1200 km – 15 bands VNIR*

- High Resolution (HR)
  - Landsat 8 *30 m – swath 180 km – 8 bands VNIR-SWIR (+TIR)*
  - DMC-2 / DEIMOS *22 m – swath 650 km – 3 bands VNIR*
  - Gaofen WF *16 m – swath 800 km – 4 bands VNIR*
  - Sentinel-2 (A / B) *10-20 m – swath 290 km – 13 bands VNIR-SWIR*
  - SPOT 6 / SPOT 7 *6 m – swath 60 km – 4 bands VNIR*
  - and many others smaller missions

Monitoring crop with satellite images

The NDVI, an old and most popular index

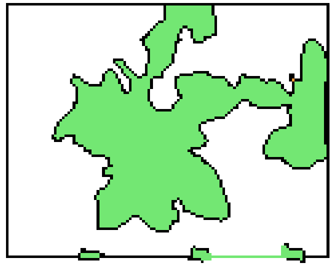
- Normalized Difference Vegetation Index : $\frac{NIR-Red}{NIR+Red}$

- Advantages
  - very simple to use
  - characterizes development of the vegetation *(green)*
  - insensitive to cast shadows and canopy 'darkness' *(surface shadows of rough canopies: shrubs, trees …)* and rather insensitive to 'greenness' of foliage *(chlorophyll level)*

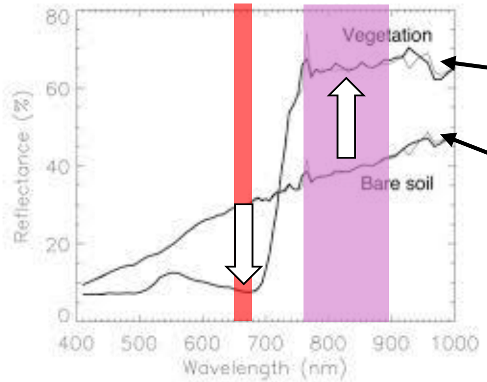
- Limitations
  - dependent on data processing level *(raw, calibrated, reflectance …)* and sensor source
  - major drawback : close to maximum after canopy closure, 'saturation effect'
  - sensitive to cloud veils, soil color, presence of brown vegetation *(NPV= non photosynthetic) …*

How can we physically characterize Crop development ?

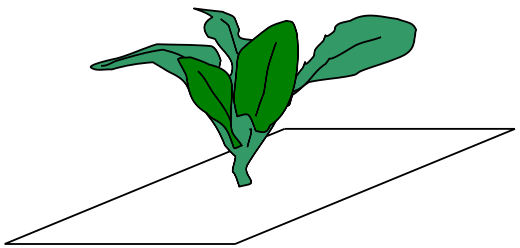
Fractional Cover of Vegetation (fCover)



(% of cover seen from above)

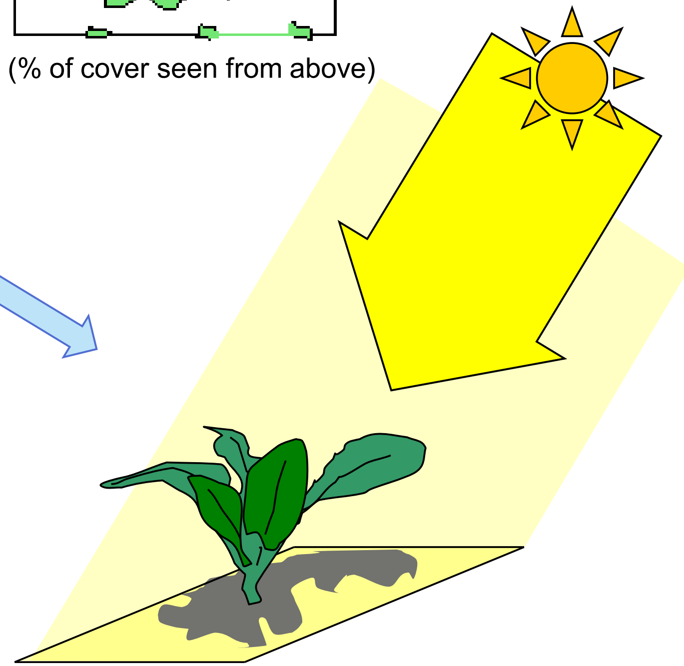


NDVI



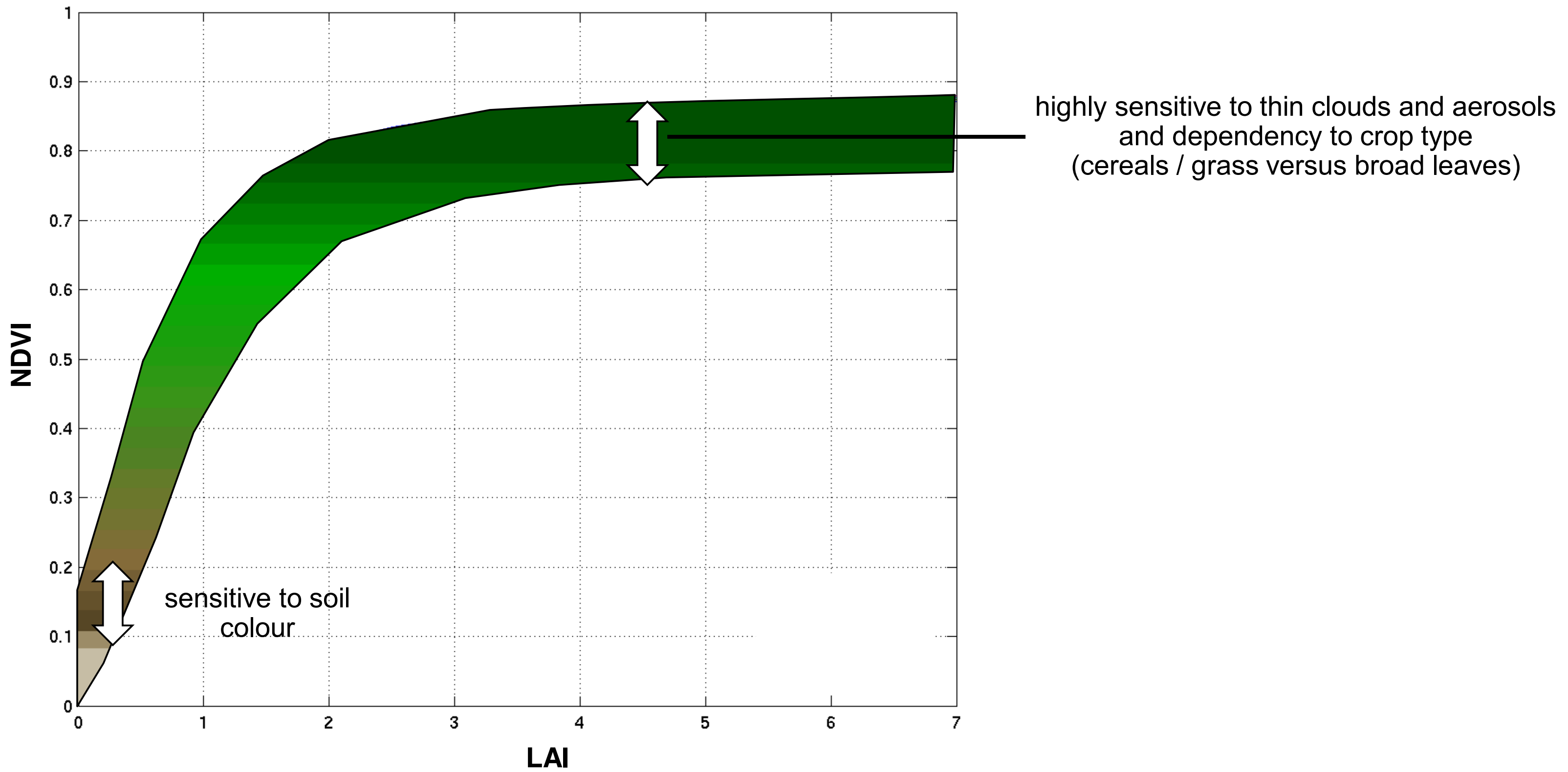
(m² of leaves per m² of ground)

Leaf Area Index (LAI)



Fraction of Absorbed Photosynthetically Active Radiation (FAPAR)

Limitations of NDVI



- NDVI is
  - good to capture emergence and early development
  - poor to measure differences of ‘density’ or ‘vigor’ once crop established

Alternatives to NDVI

- Other empirical Vegetation Indices
  - a wealth of indices derived from NDVI being proposed *(PVI, SAVI, ARVI, GEMI, …)* exploiting additional bands to further correct for soil, atmosphere, directional effects … NDVI still the most used
  - indices based on other bands proposed, but much less success *(PRI, ..)*

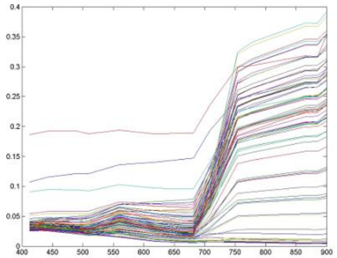
- Reflectance Modelling approach
  - idea is to fully simulate the optical response *(i.e. reflectance)* of a vegetation canopy, in the VNIR-SWIR domain
  - needs as well to use models for the transfer through the atmosphere
  - model inversion = process of retrieving values of the input parameters that explain the measured reflectance

⇨ This approach, so called biophysical processing, is getting more and more momentum in the research and operational remote sensing community

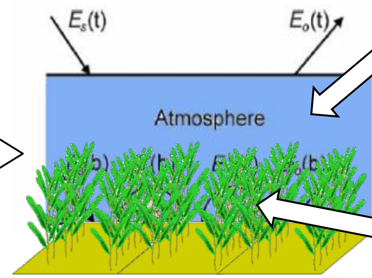
Example of a solution for biophysical processing *(Overland)*

raw image

generation of 'Top Of Atmosphere' reflectance - extraction of cells in spectral domain



MODTRAN + cloud model for the atmosphere



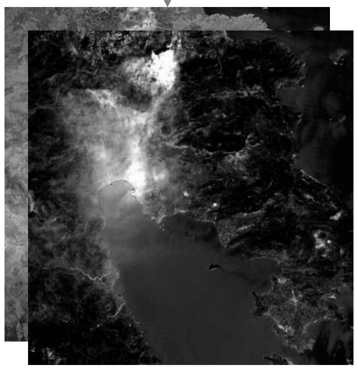
SAIL / PROSPECT models for the vegetation canopy

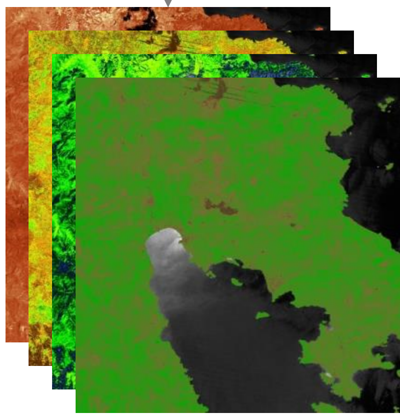
BRDF model of scene and atmosphere

model inversion through minimisation (solution + local linear inverse model)

generation of biophysical maps

information layers for atmospheric conditions (clouds and aerosols)

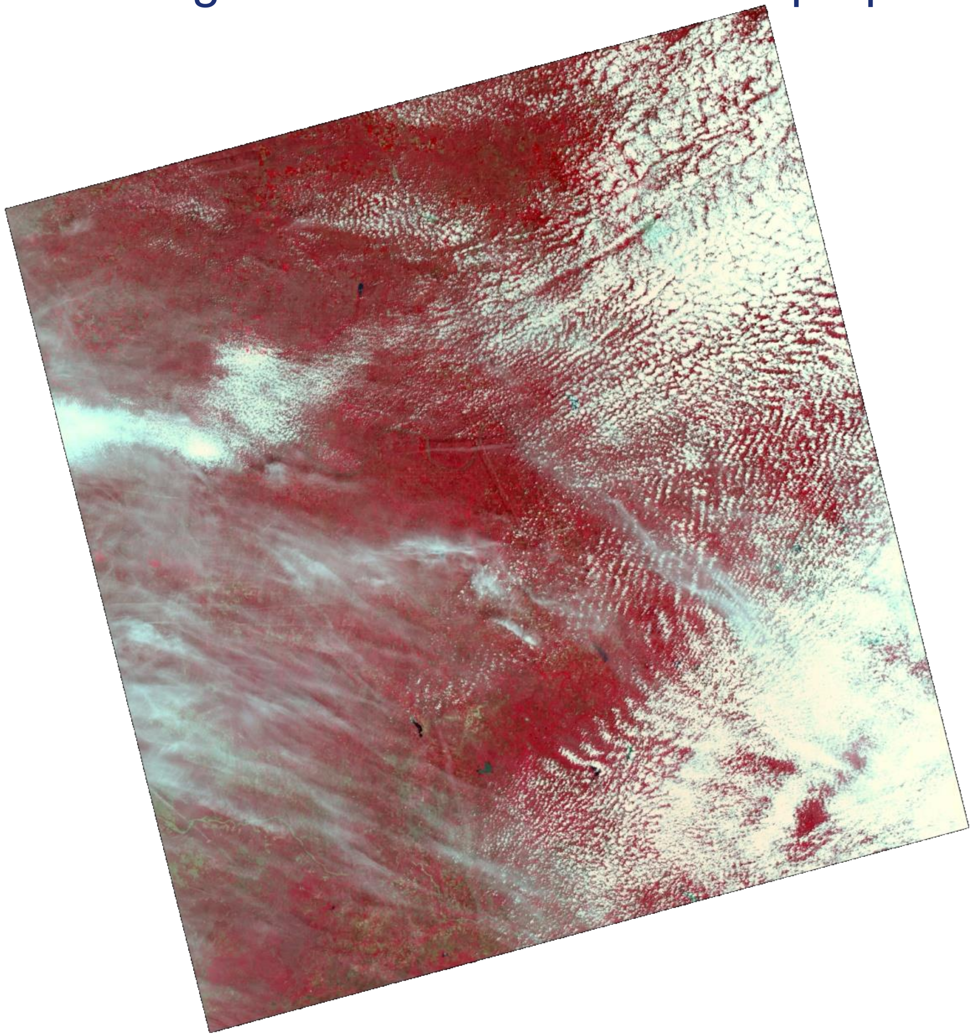




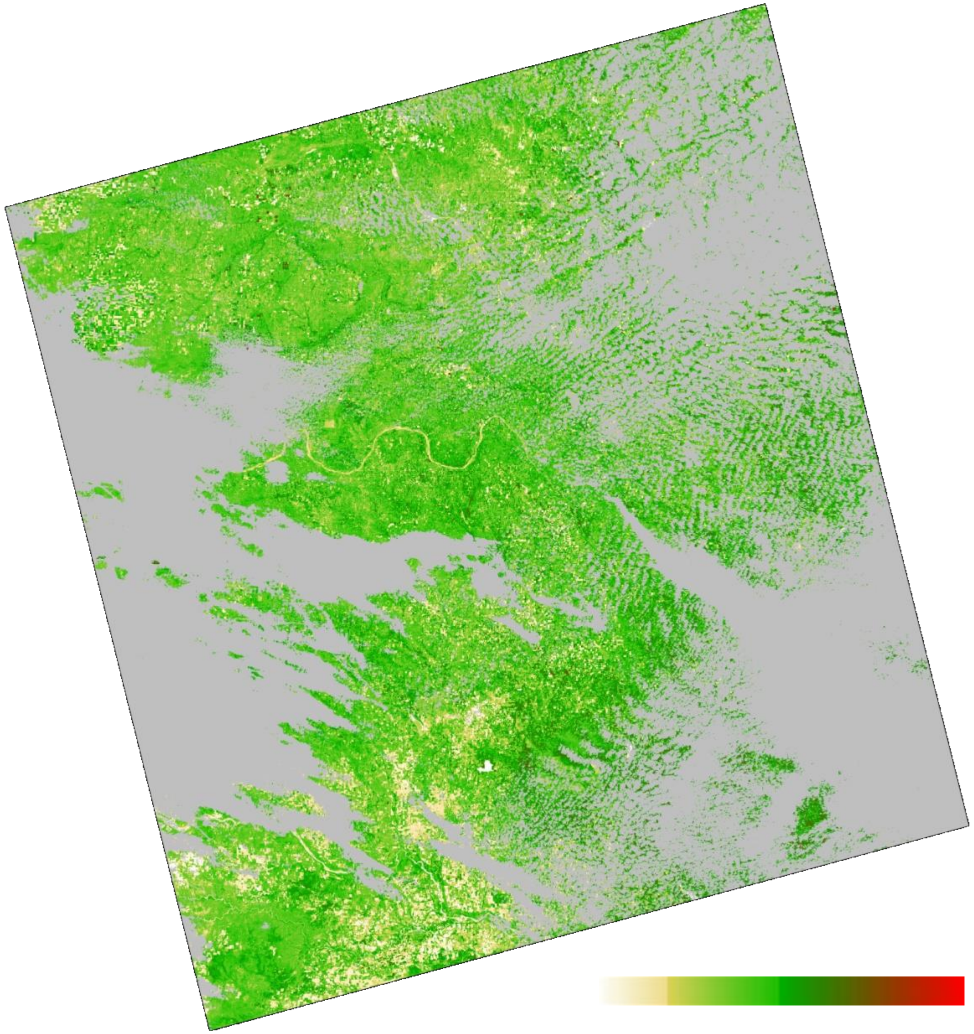
information layers for vegetation and soil

Biophysical processing versus NDVI

achieving better robustness with a proper veil detection / correction



DMC-2 image with clouds and veils
(NIR colour composite)



fCover map – with similar colour scale –
(correct for 'dampening' on cloud veil areas)

DEFENCE & SPACE

Biophysical information at global scale / low resolution (LR)

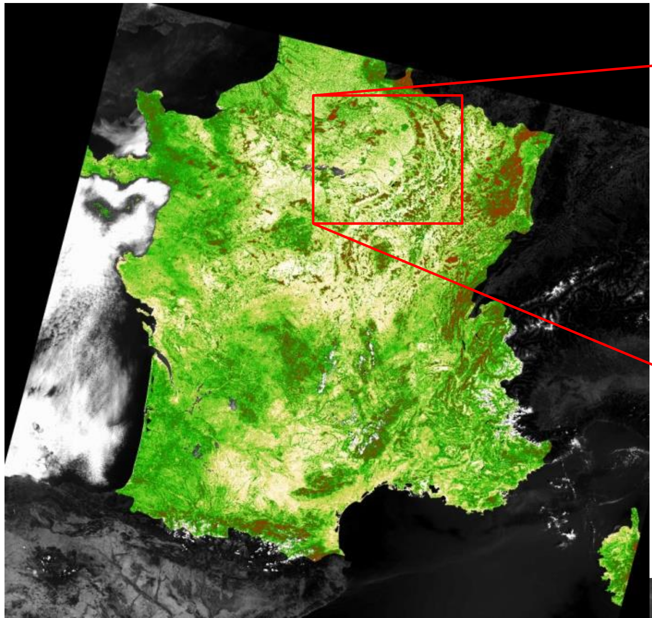
- Key facts
  - well developed remote sensing community with major efforts for validating / qualifying operational biophysical products
  - focuses on describing mean evolution of the vegetation cover *(composite nature of LR pixel)* through parameters like FAPAR / LAI / fCover
  - achievable frequency with LR missions : every 10 days using compositing techniques *(consolidation of information from multiple, partially cloudy images)*
  - interest of having long term series since first EO LR satellites *(AVHRR, 1978)*
  - possibility to retrieve canopy specific information through disaggregation techniques *(having knowledge of detailed Land Cover)*
  - strong interest in improving spatial resolution *(i.e. down from 1 km to 300 … 100 m)* while keeping global mapping capability

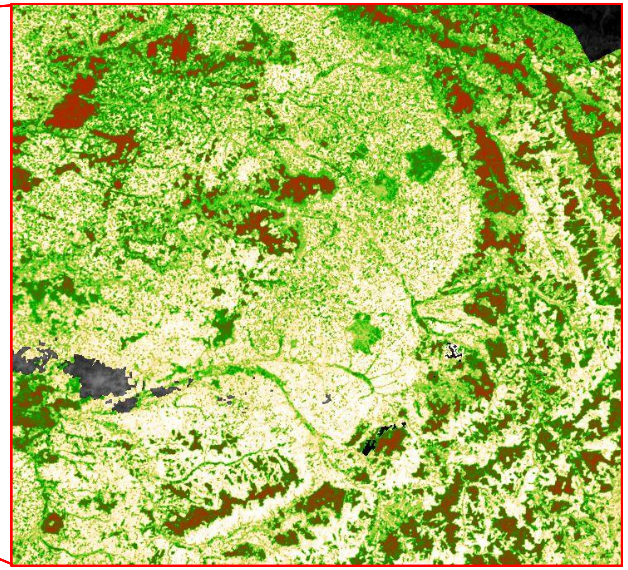
Biophysical information at global scale / low resolution (LR)

- Operational production lines

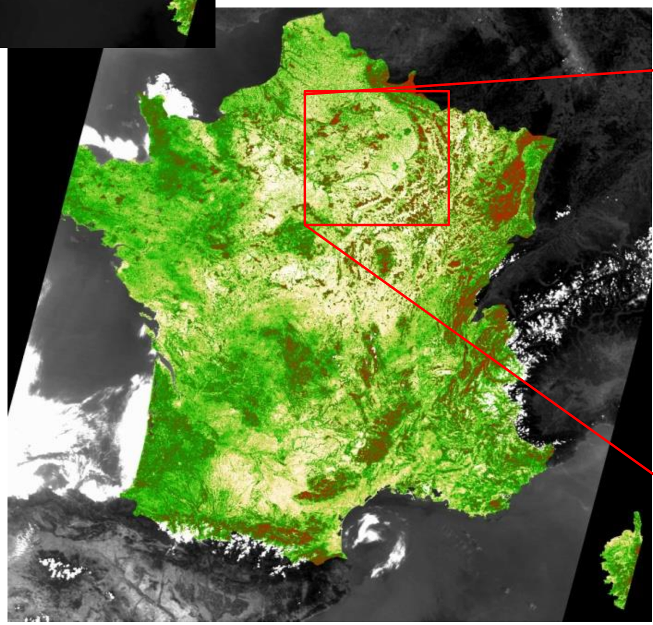
Name	producer	sensor data	coverage	period	Vegetation Indices	Vegetation parameters		
						FAPAR	LAI	fCover
MODIS products	USGS *(public)*	MODIS Terra/Aqua	global	2000 –	**NDVI** *(250 m)* **/ EVI** *(500 m)* 8 days	*(1 km)* 8 days	*(1 km)* 8 days	—
Copernicus Global Land Service	EC / ESA *(public)*	VGT and AVRHRR	global	1998 –	**NDVI** *(1 km)* 10 days	*(1 km)* 10 days	*(1 km)* 10 days	*(1 km)* 10 days
BioPar MR	Airbus DS *(internal use)*	MERIS / MODIS	regional *(Europe)*	2000 –	—	*(300 m)* 10 days	*(300 m)* 10 days	*(300 m)* 10 days

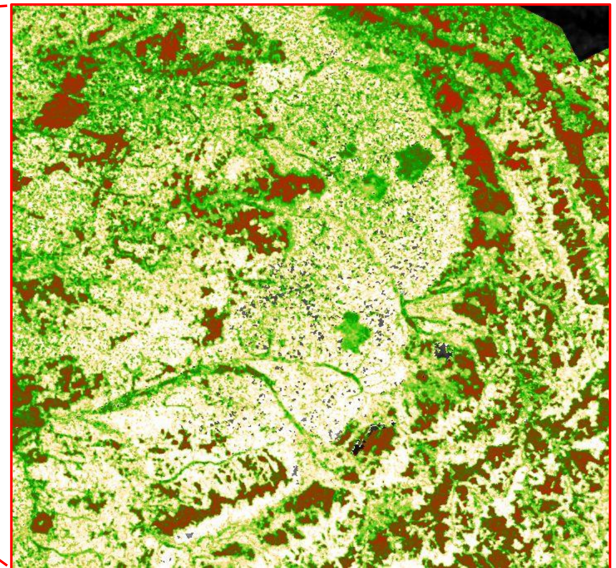
Concept of sensor independent information – example of MERIS / MODIS comparison





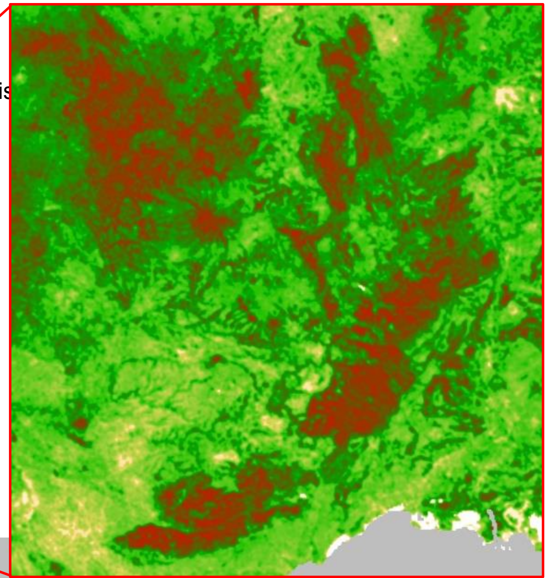
MERIS FAPAR map
(12th August 2003)



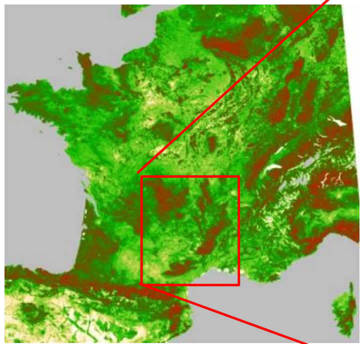


MODIS FAPAR map (composite 10-12 August 2003)

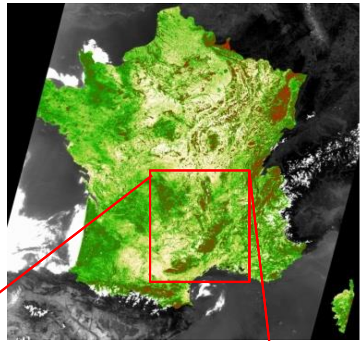
Comparison of several production – interest of a better resolution –



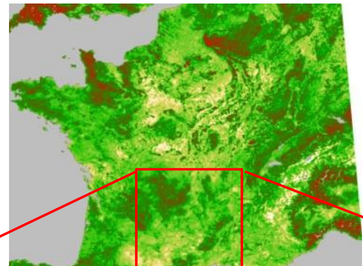
geoland2 VGT @ 1 km

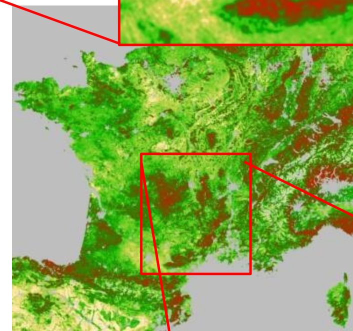


FAPAR Airbus-GEO @ 300 m

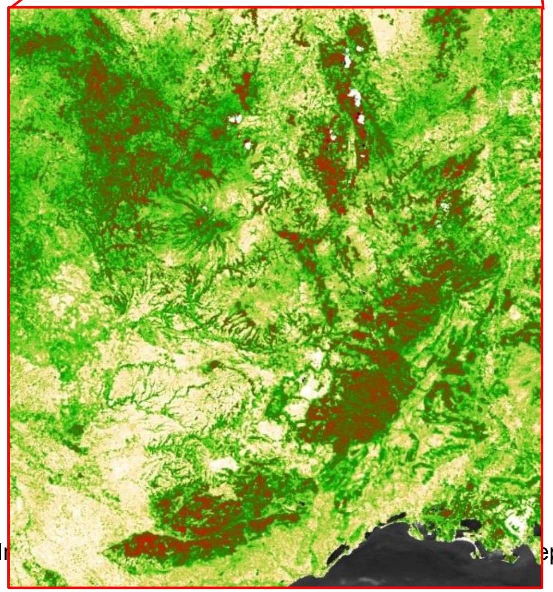


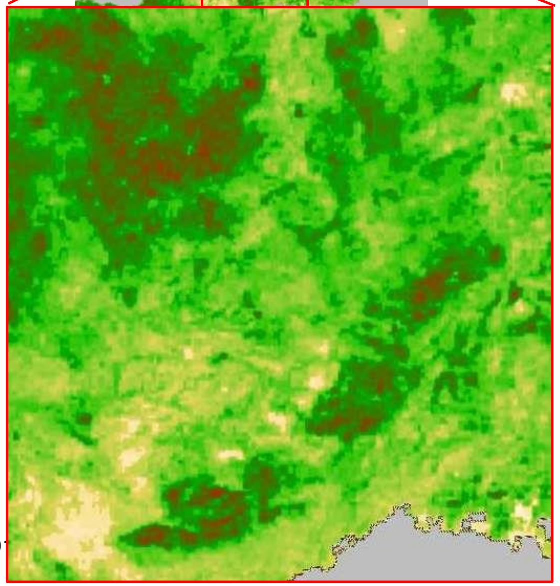
JRC FAPAR @ 2 km

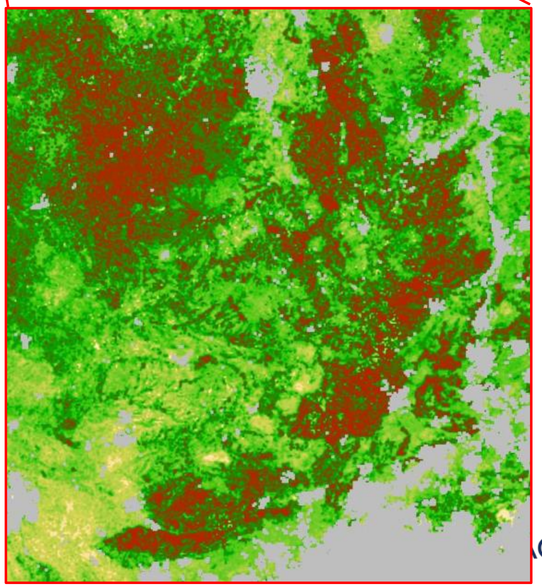




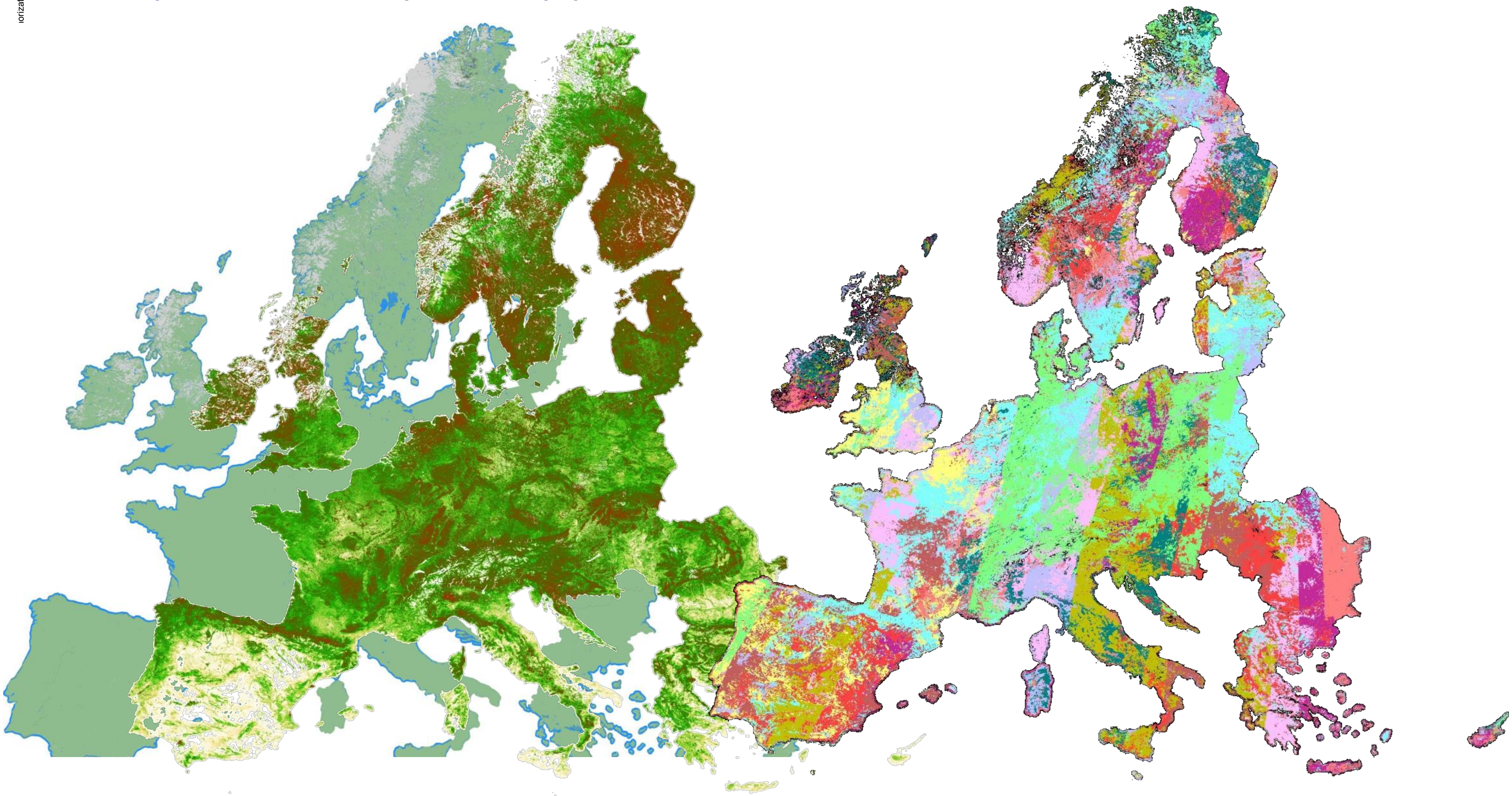
MOD15 FAPAR @ 1 km







Example of Pan-European map produced from MERIS data



FAPAR map

0 *1*

Compositing performed over the period for this result
(1 different colour per day)

AIRBUS
DEFENCE & SPACE

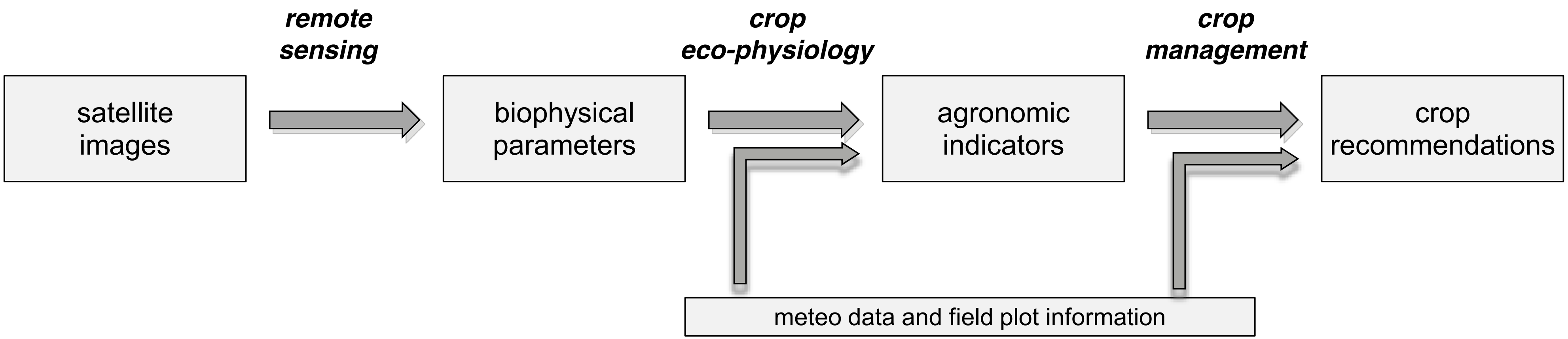
Biophysical information at regional scale / high resolution (HR)

- Key facts
  - achievable frequency by consolidating data from various HR missions : every 2 to 4 weeks
  - challenge will be to collect and process large volume of heterogeneous data
    (many sensors, different spatial and spectral resolutions, different distribution channels)
  - international initiatives from the remote sensing community to support world regional monitoring for food security (GEOGLAM, ..)
  - research focuses on
    - mapping areas of active cropping
    - extracting key parameters that characterizes the crop cycle from 3 – 5 observations randomly made along the season
  - creation of commercial services for crop management (‘precision farming’)
  - with new sensors having more spectral bands, access to additional information to feed crop-specific analysis
    - chlorophyll content *(plant nutrition)*
    - % of dry leaves *(stress and maturity)*

AIRBUS DEFENCE & SPACE

Biophysical HR / crop management services (precision farming)

- Description
  - spatial resolution : 5 – 20 m
  - service targets critical dates for management decision along the crop cycle
  - use of core parameters LAI, fCover and Chlorophyll
  - combined with agronomic science / decision rules for agriculture local practices to generate end-user products

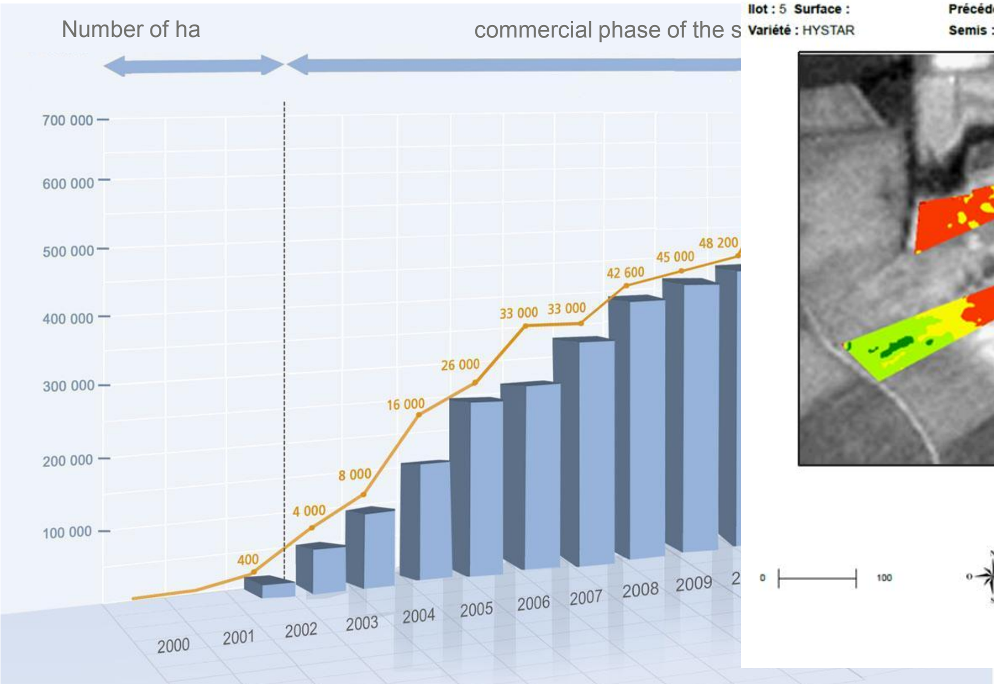


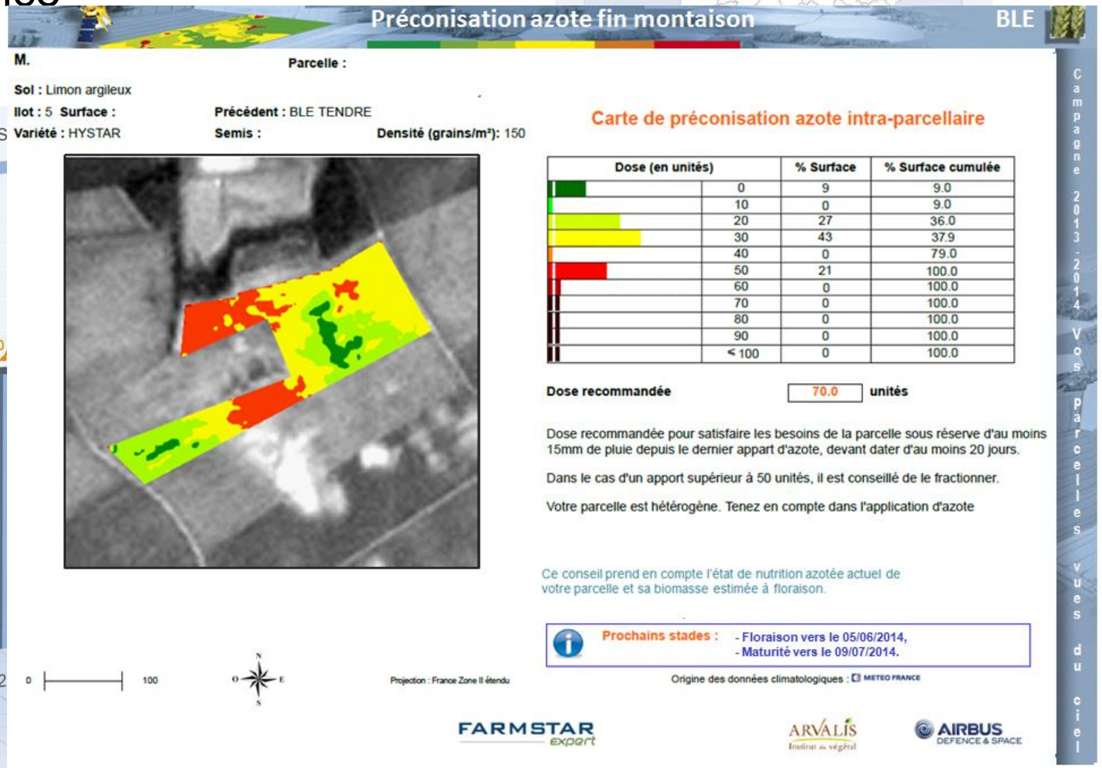
AIRBUS DEFENCE & SPACE

Biophysical HR / example of the Farmstar service

Operated commercially since 2002

- partnership Arvalis / Airbus
- distributed through cooperatives *(crop growers are end-users)*
- addressing winter crops *(wheat / rapeseed / barley)*
- covering major cropping regions in France





Préconisation azote fin montaison — BLE

M. — Parcelle :

Sol : Limon argileux

Ilot : 5 Surface : — Précédent : BLE TENDRE

Variété : HYSTAR — Semis : — Densité (grains/m²): 150

Carte de préconisation azote intra-parcellaire

Dose (en unités)	% Surface	% Surface cumulée
0	9	9.0
10	0	9.0
20	27	36.0
30	43	37.9
40	0	79.0
50	21	100.0
60	0	100.0
70	0	100.0
80	0	100.0
90	0	100.0
< 100	0	100.0

Dose recommandée 70.0 unités

Dose recommandée pour satisfaire les besoins de la parcelle sous réserve d'au moins 15mm de pluie depuis le dernier appart d'azote, devant dater d'au moins 20 jours.

Dans le cas d'un apport supérieur à 50 unités, il est conseillé de le fractionner.

Votre parcelle est hétérogène. Tenez en compte dans l'application d'azote

Ce conseil prend en compte l'état de nutrition azotée actuel de votre parcelle et sa biomasse estimée à floraison.

Prochains stades : - Floraison vers le 05/06/2014, - Maturité vers le 09/07/2014.

0 — 100

Projection : France Zone II étendu

Origine des données climatologiques : METEO FRANCE

FARMSTAR expert — ARVALIS Institut du végétal — AIRBUS DEFENCE & SPACE

Campagne 2013-2014 Vos parcelles vues du ciel

AIRBUS DEFENCE & SPACE

Conclusions

- Remote Sensing science has developed optical models of the vegetation canopy, being more and more accurate
- Operational use of these models to interpret satellite images
  - can be more powerful and robust than simple indices
  - can better exploit the spectral richness of new sensors data
  - can give access to multiple and more specific information
- Biophysical information maps already available at global scale / low resolution
  - mission continuity ensured by major space agencies
  - strong interest in improving spatial resolution
- Same techniques applicable to high resolution data for interpretation at field plot level
  - many new satellite missions, combination of sources increases revisit
  - challenge is to get access and process data from these multiple sources

Thanks for your attention

UNIVERSITY OF TWENTE.

REMOTE SENSING FOR INSURING EAST AFRICAN PASTORALISTS: OVERVIEW AND INDEX DESIGN

Anton Vrieling

(+ Andrew Mude, Michele Meroni, Sommarat Chantarat, and others)

16 September 2015 – Global Index Insurance Conference, Paris, France
side event “Index insurance: risk sharing & challenges – 17:15-17:45

ITC FACULTY OF GEO-INFORMATION SCIENCE AND EARTH OBSERVATION

MY RESEARCH LINK TO INSURANCE

- de Leeuw J, A Vrieling, A Shee, C Atzberger, K Hadgu, C Biradar, H Keah, C Turvey, 2015. The potential and uptake of remote sensing in insurance: a review. *Remote Sensing, 6*, 10888-10912

- Vrieling A, M Meroni, A Shee, AG Mude, J Woodard, CAJM de Bie, F Rembold, 2014. Historical extension of operational NDVI products for livestock insurance in Kenya. *International Journal of Applied Earth Observation and Geoinformation, 28*, 238-251

- Vrieling A, M Meroni, AG Mude, S Chantarat, CC Ummenhofer, CAJM de Bie, 2015. Early assessment of seasonal forage availability for mitigating the impact of drought on East African pastoralists. *In revision*.

CONTENT

- RS for insurance: short overview
- Index-based livestock insurance in East Africa
  - Introducing IBLI
  - From asset replacement to asset protection (RS research)
  - Challenges: RS-related challenges for IBLI

RS FOR INSURANCE

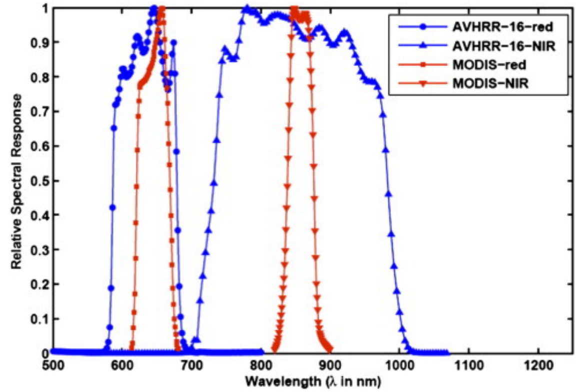
- RS community since 1970s suggested potential
  - Possible to assess damage: fire, hail, drought
  - Focus on technical capabilities
- Nonetheless, few operational insurance products use RS
  - And if so, more gov't (USDA) than private sector

- Possible explanation: most proposed RS applications aim to automate industry's existing business processes (e.g. damage assessment, underwriting risk)
  - Better to eliminate processes → index insurance
    - Avoid handling/verification claims
    - Avoid costs imposed by fraud, moral hazard, adverse selection
    - Develop new markets + replace traditional agri-insurance?

INDEX REQUIREMENTS

1. strong correlation with what is insured
2. independently verifiable, i.e. based on well-described data sources and processing methods
3. reliable delivery into future + available in near real-time
4. available for sufficiently long period to properly represent climatic variability → payout probability and pricing
5. information gathering at limited cost for insurer

CHALLENGES RS FOR INDEX INSURANCE



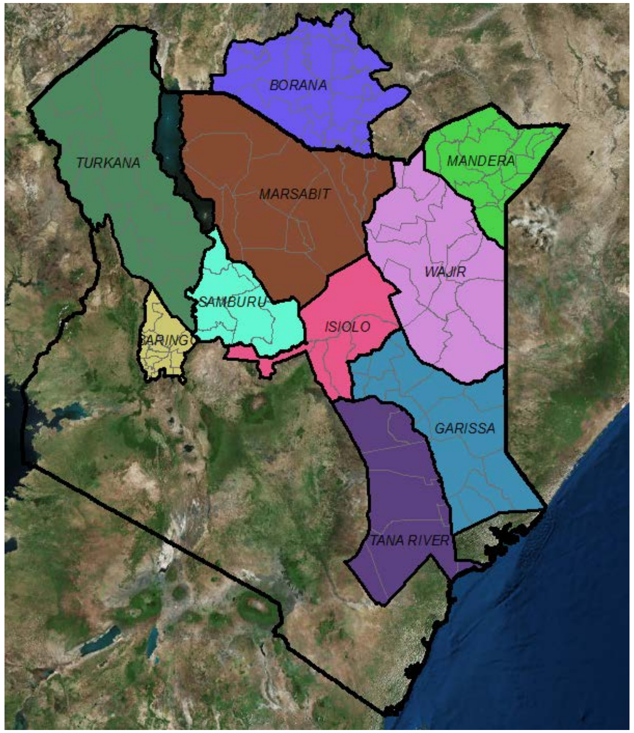
1. Data continuity & compatibility
2. Data quality
   - Rainfall: performance vis-à-vis *in situ*?
   - Vegetation:
     - noise in optical systems (atmosphere, clouds)
     - sensitivity to background (soil colour)
3. Spatial detail (resolution): what do we monitor?
4. Low basis risk (or high insurance quality)
   - index to correlate with losses / life quality and meet demand
     1) Index construction: vegetation/rainfall + options!
     2) Calibration / validation options
        - Lack of good crop/livestock statistics
        - Insurance is often single peril, but yield reflects multiple perils

INDEX-BASED LIVESTOCK INSURANCE KENYA / ETHIOPIA

ILRI
INTERNATIONAL LIVESTOCK RESEARCH INSTITUTE

- Horn of Africa:
  - > 20 million pastoralists that depend on livestock
  - exports of livestock & livestock products > $1billion
  - drought is main cause of livestock loss → source of poverty
  - standard responses (food/cash aid) are slow, costly, and insufficient

- 2010: IBLI started in Marsabit
  - gradual expansion
  - Contract purchased Jan-Feb 2015:
    - > 2500 in Kenya (Garissa, Isiolo, Mandera, Marsabit, Wajir)
  - KLIP to start offering free insurance
    - Up to 5 TLU for targeted beneficiaries

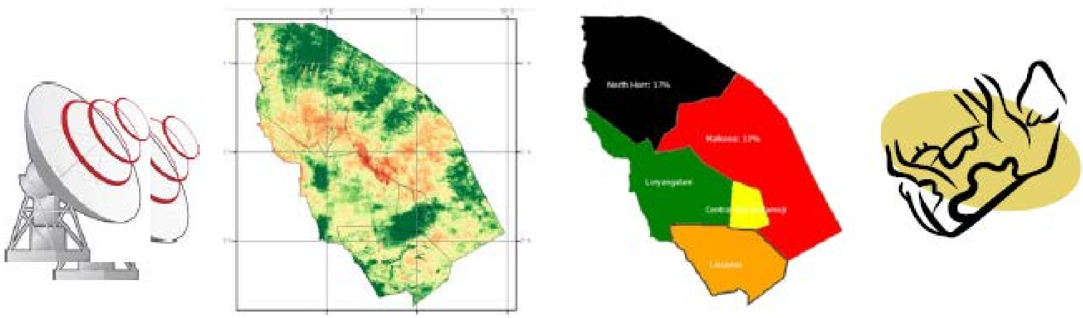


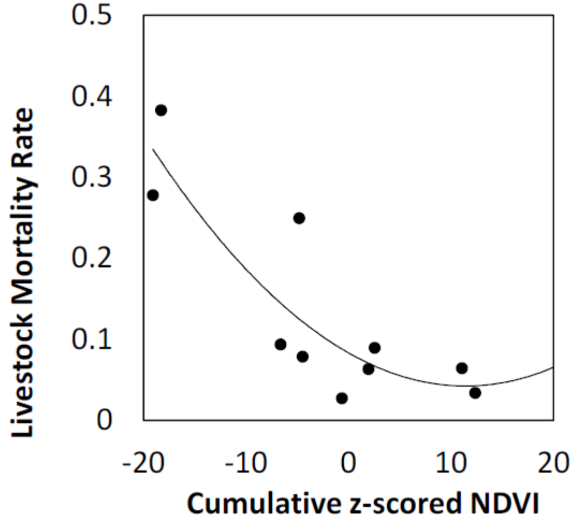
UNIVERSITY OF TWENTE.

IBLI: INITIAL LOGIC

- **First Contract: Marsabit – January 2010 – January 2013**
  - **Response Function**: Regress historic livestock mortality data onto satellite Normalized Differenced Vegetation Index (NDVI) – based proxy of area-average forage availability
  - IBLI Contract is for **Asset Replacement**: Pays out when forage scarcity is predicted to cause livestock **deaths** in an area

DATA → **Response Function** → **Index**





UNIVERSITY OF TWENTE.

Chantarat, S., Mude, A.G., Barrett, C.B., & Carter, M.R. (2013). Designing index-based livestock insurance for managing asset risk in northern Kenya. *Journal of Risk and Insurance, 80*, 205-237

IBLI: MOVING BEYOND MARSABIT

- **ALRMP Livestock Mortality Data** – increasing gaps
  - Design complexity, data scarcity, precision concern

⇩

- NDVI-only contracts: *area-average seasonal forage availability compared to historical seasons*
- July 2012 in Borana (no mortality data) – Oromiya Insurance Company
  - *easier to explain and scale up*

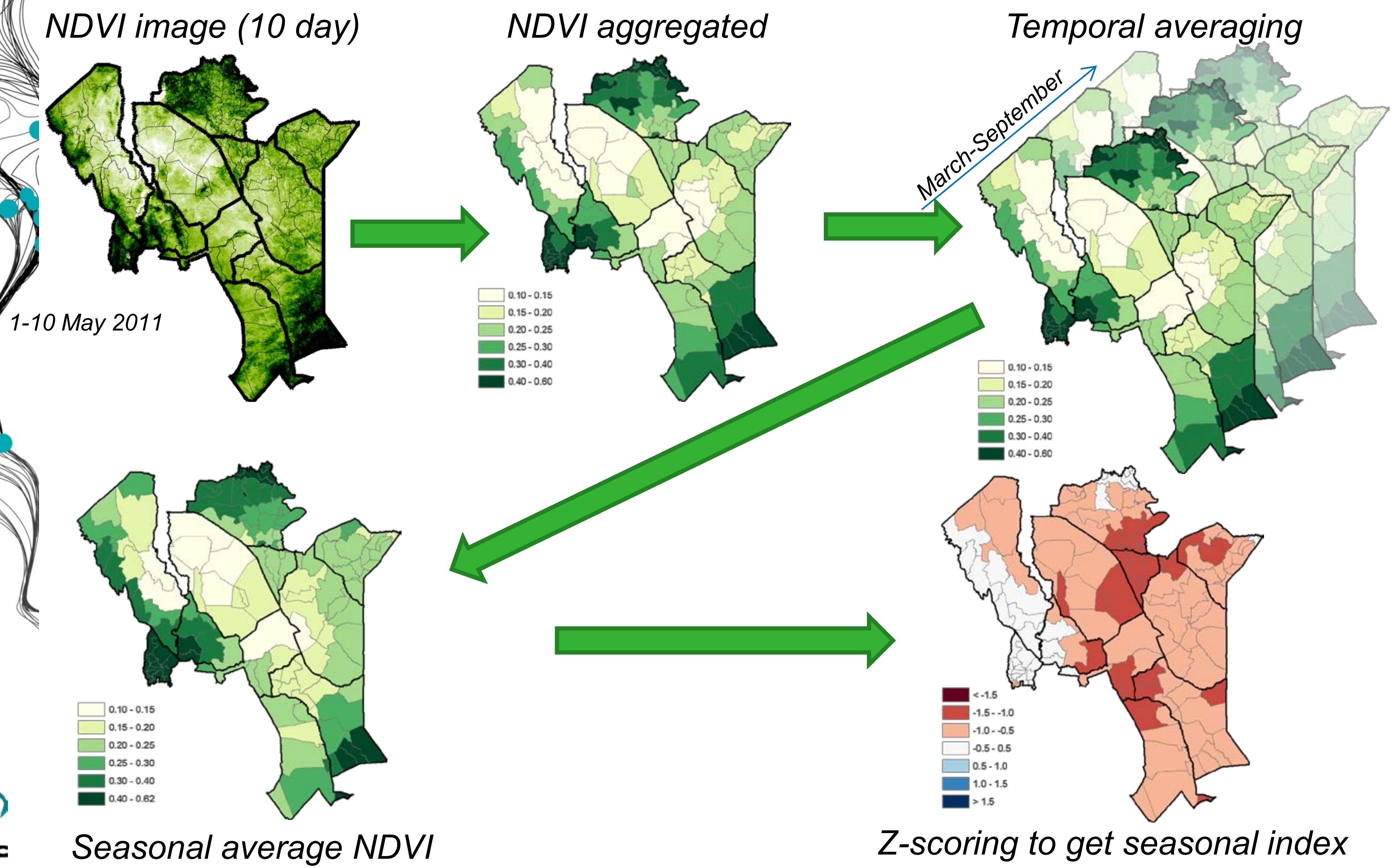
- **KLIP:** move to **asset protection →** intervention prior to mortality
  - Payout at the beginning of the dry season rather than the end
  - Insured unit: cost to keep livestock alive during drought
  - APA Insurance (Marsabit and Isiolo), Takaful Insurance of Africa (Wajir, Isiolo, Mandera, Garissa) launched asset protection contracts in January 2015

FORAGE SCARCITY INDEX (1): FROM NDVI TO INDEX

- GOAL: indicator of seasonal forage availability within an insurance unit, relative to 'normal' availability

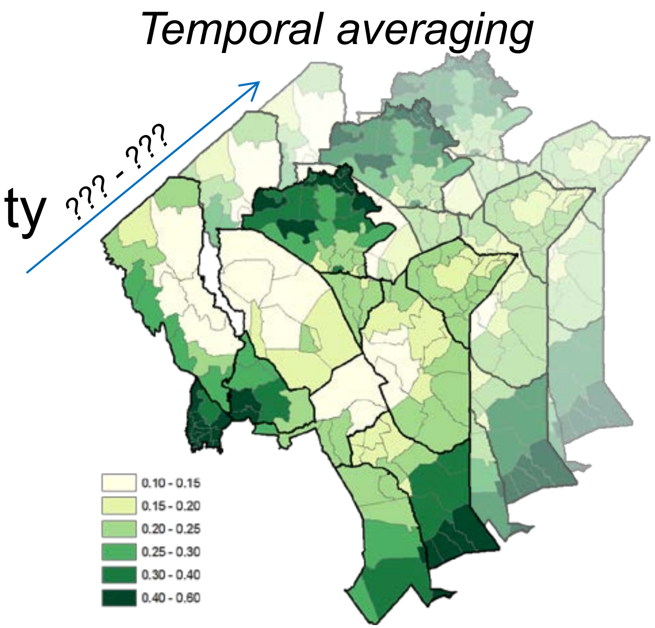
* Vrieling, A., Meroni, M., Shee, A., Mude, A.G., Woodard, J., de Bie, C.A.J.M., Rembold, F., 2014. Historical extension of operational NDVI products for livestock insurance in Kenya. International Journal of Applied Earth Observation and Geoinformation 28, 238-251.

FORAGE SCARCITY INDEX (2): APPROACH *



TOWARDS ASSET PROTECTION

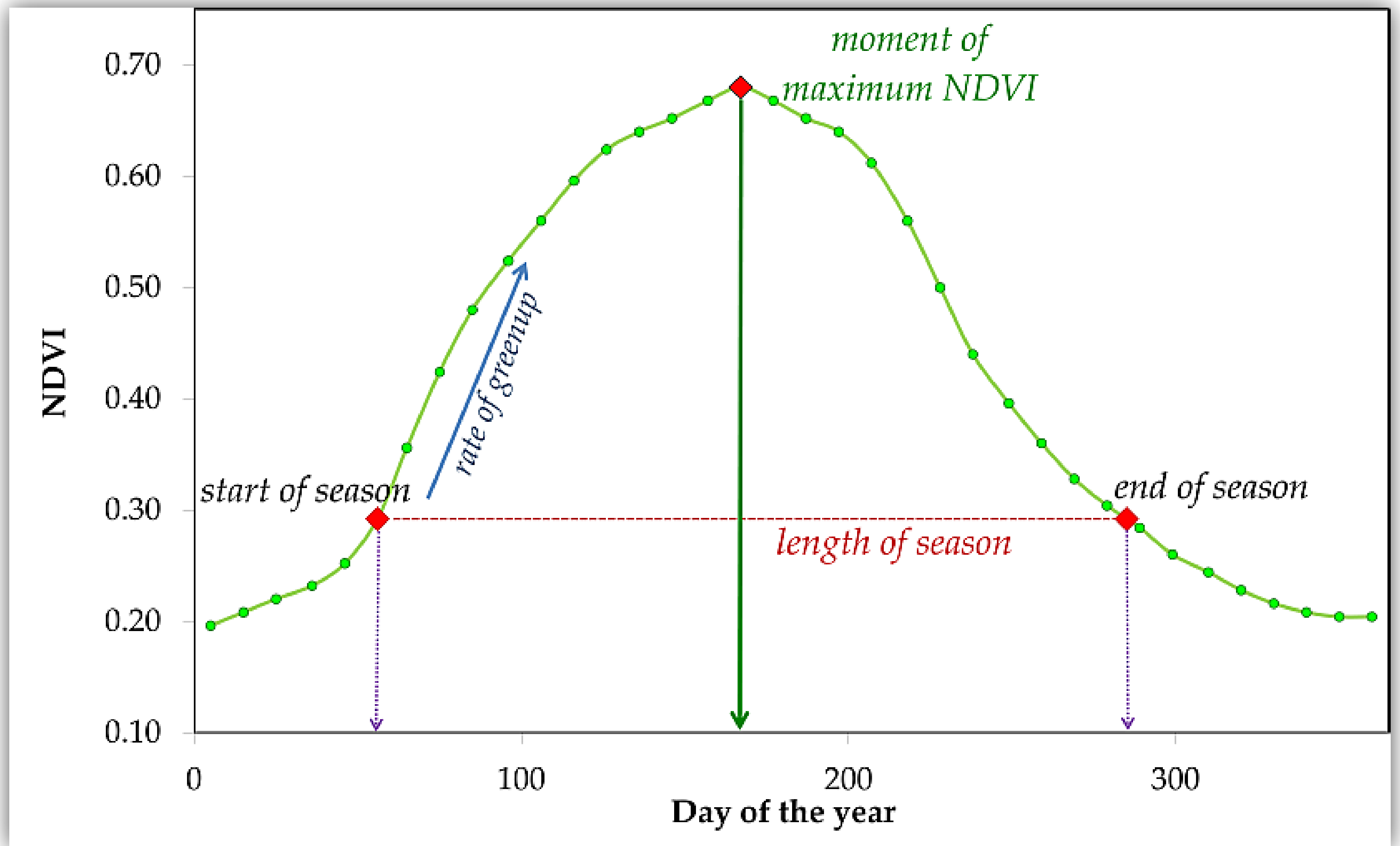
- RS-options exist for earlier payout, but require *to better identify the temporal integration period* for IBLI's forage scarcity index
  - unit-specific
  - phenological analysis
  - predictability of end-of-season variability



- Asset replacement vs asset protection
  - early assessment → early payout
- Now:
  - LRLD: March – September
  - SRSD: October – February (payout ideally 1 month later)
- BUT: focus on green biomass build-up only!

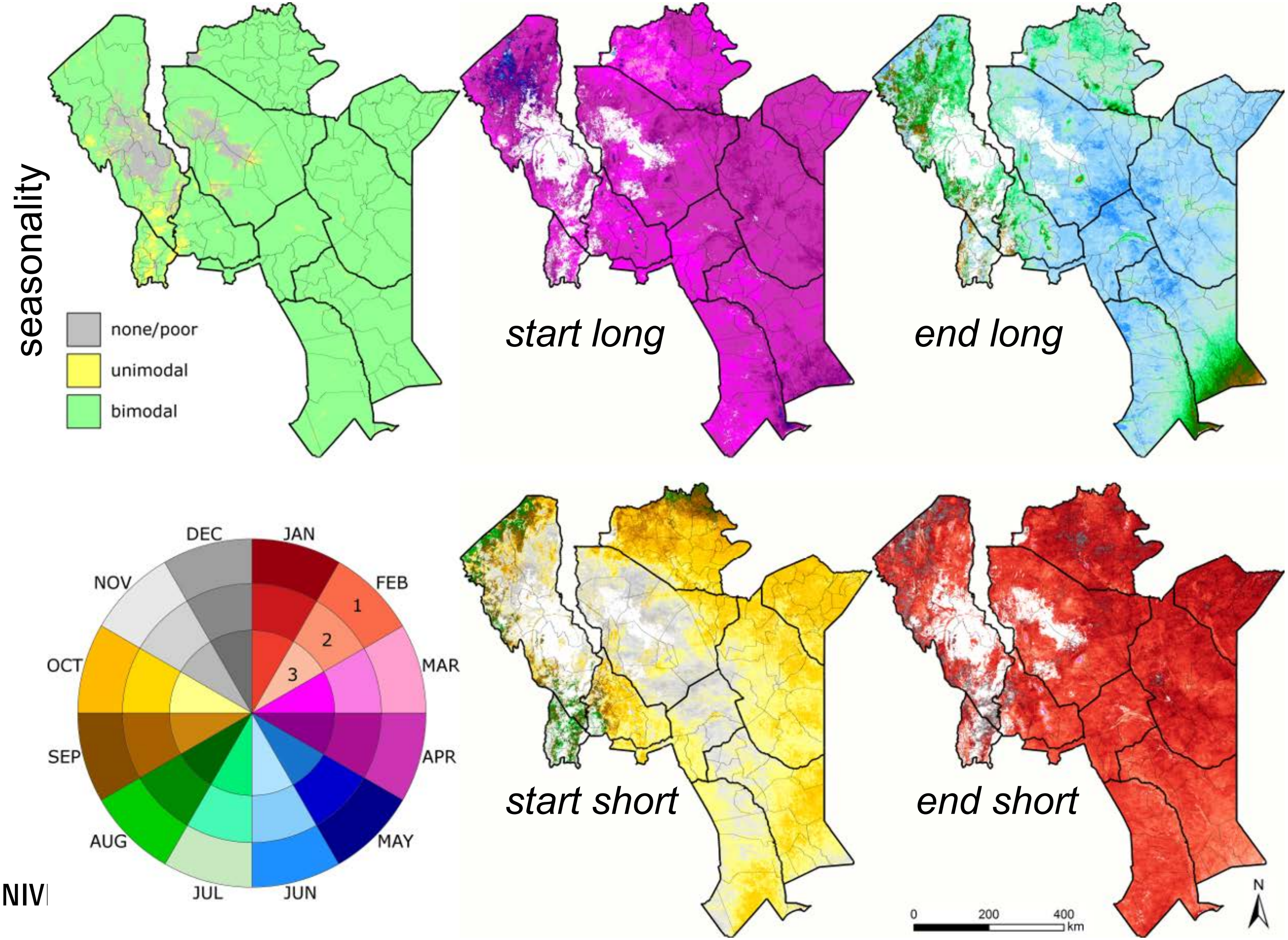
PHENOLOGICAL ANALYSIS

For more detail, do not hesitate to ask.
Phenological analysis by Michele Meroni.



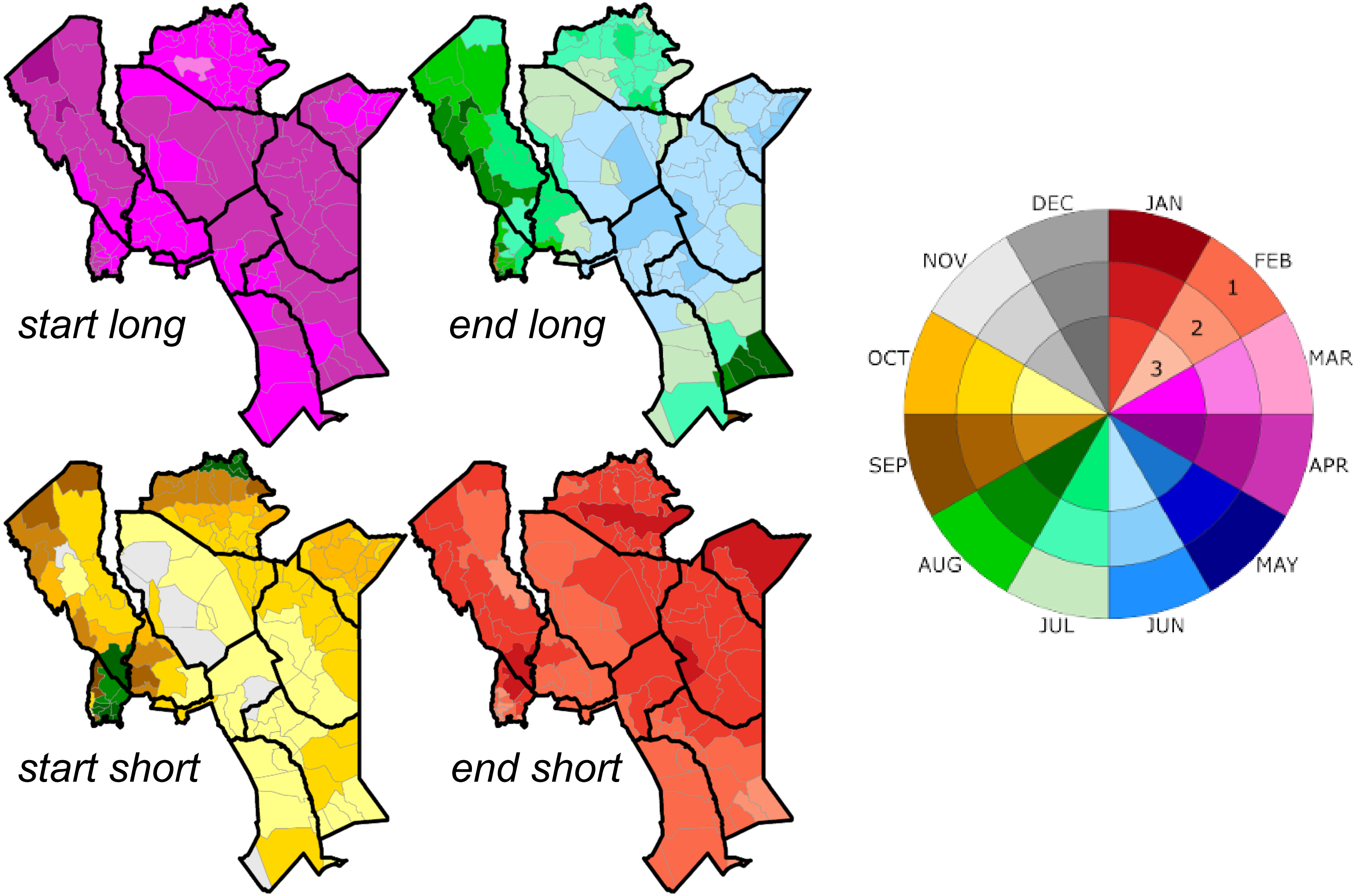
Adapted version as described in: Meroni M, MM Verstraete, F Rembold, F Urbano, and F Kayitakire. 2014. A phenology-based method to derive biomass production anomaly for food security monitoring in the Horn of Africa. International Journal of Remote Sensing, 35: 2472-2492.

PIXEL-BASED PHENOLOGY RESULTS (2001-2014 AVERAGE)



UNIV

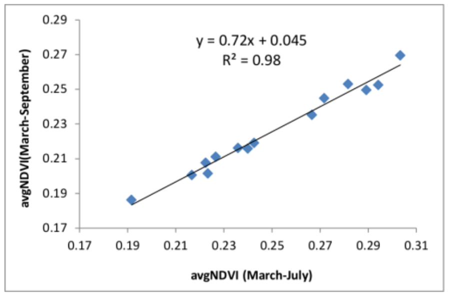
PHENOLOGY SUMMARY PER UNIT (AVG ± 0.5 SD)



CAN WE PREDICT END-OF-SEASON VARIABILITY BEFORE?

- Take as reference identified start/end

	MAR			APR			MAY			JUN			JUL			AUG			SEP			avgNDVI	avgNDVI
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	FULL	partial
2001																						0.208	0.223
2002																						0.270	0.303
2003																						0.253	0.282
2004																						0.245	0.272
2005																						0.211	0.227
2006																						0.216	0.236
2007																						0.219	0.243
2008																						0.252	0.294
2009																						0.200	0.217
2010																						0.250	0.289
2011																						0.186	0.192
2012																						0.216	0.240
2013																						0.235	0.267
2014																						0.201	0.223

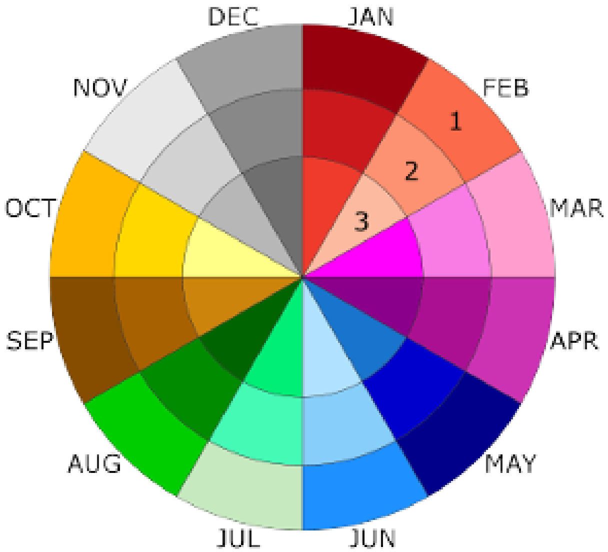


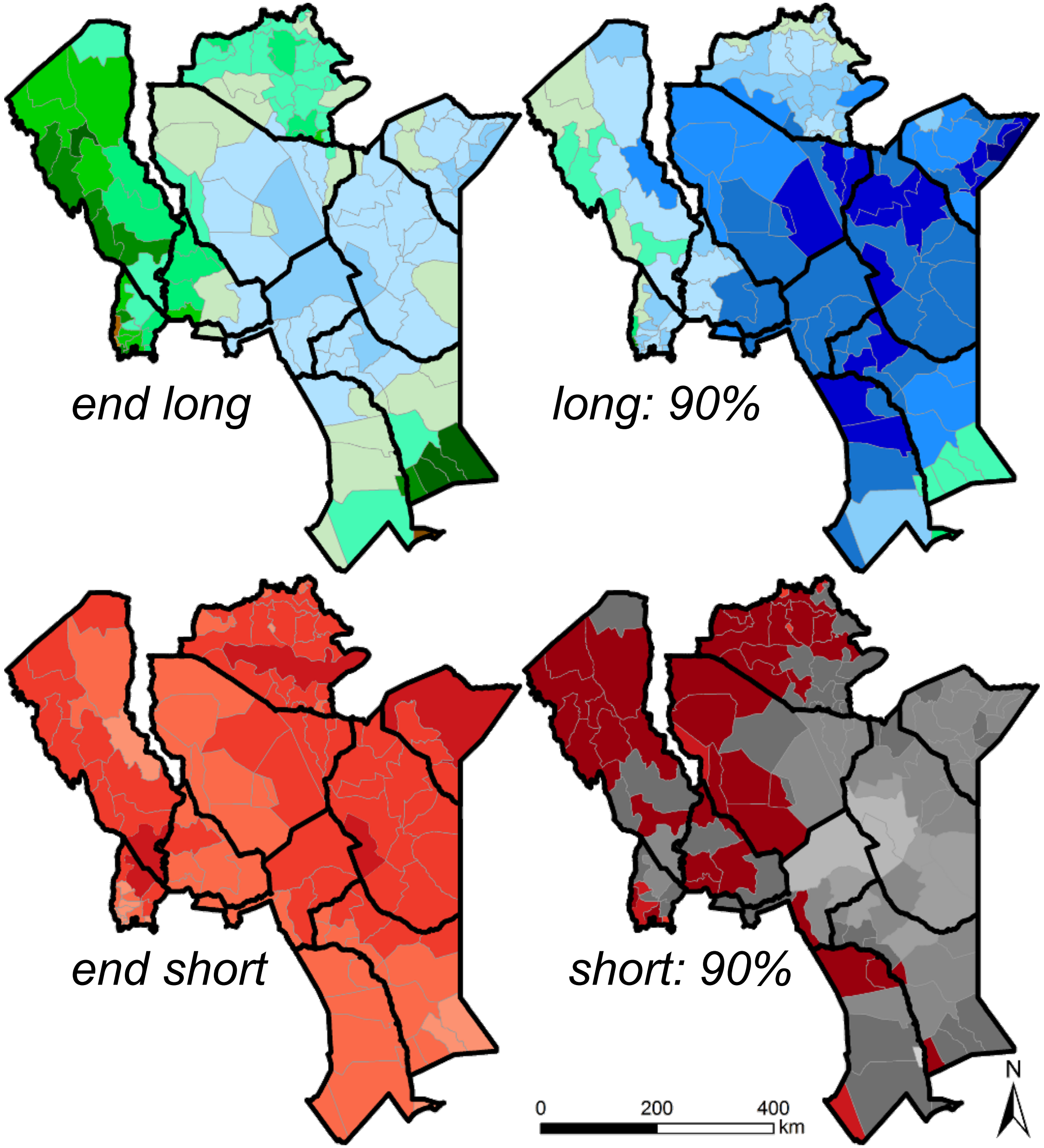
Calculate cross-validated R^2

UNIVERSITY OF TWENTE.

Example for Central Wajir (ID=96) but numbers are fictive

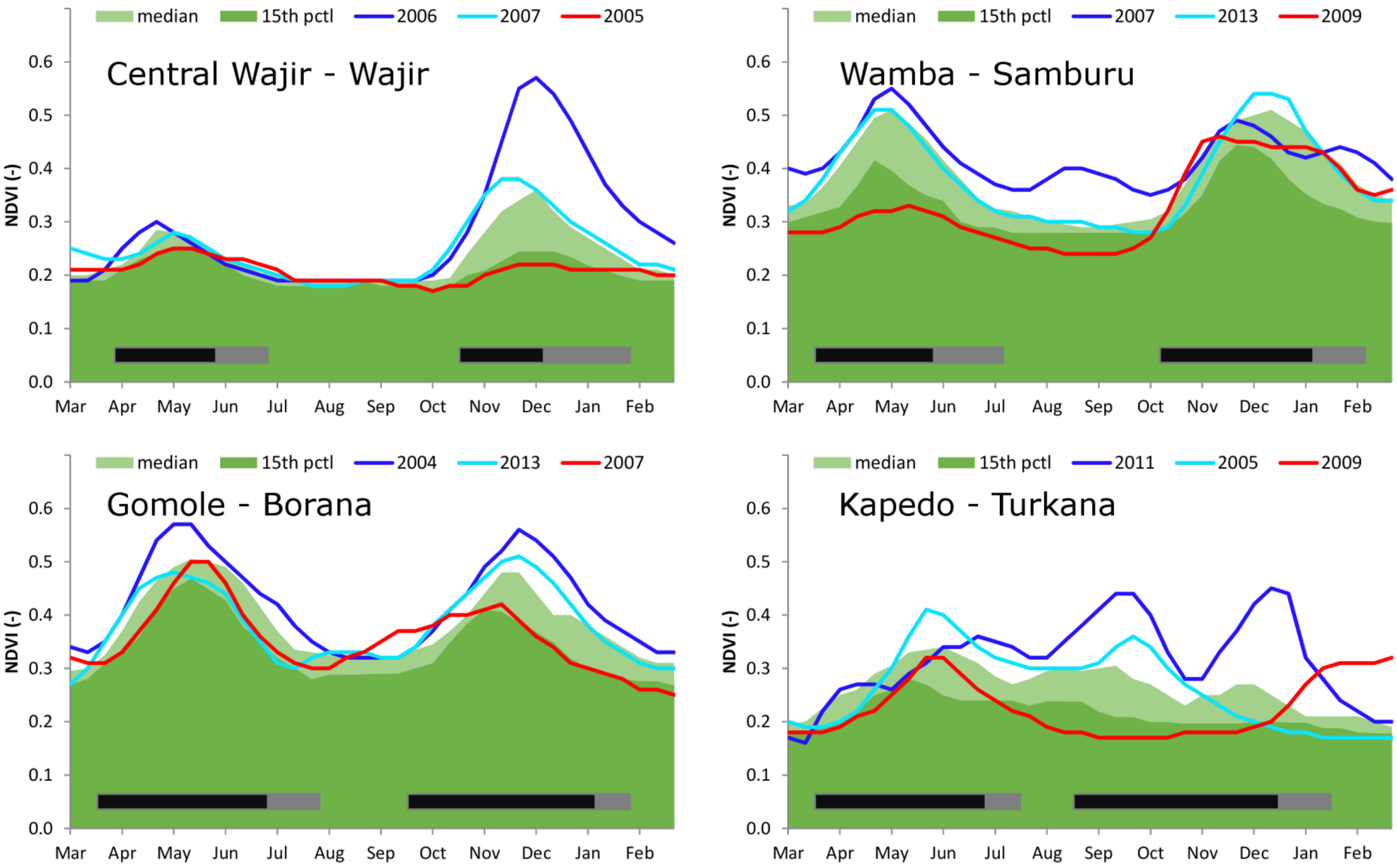
WHEN DO WE EXPLAIN 90% OF SEASON VARIABILITY?





UNIVERSITY OF TWENTE.

ILLUSTRATION FOR SEVERAL DIVISIONS



CONCLUSIONS "TOWARDS ASSET PROTECTION" WORK

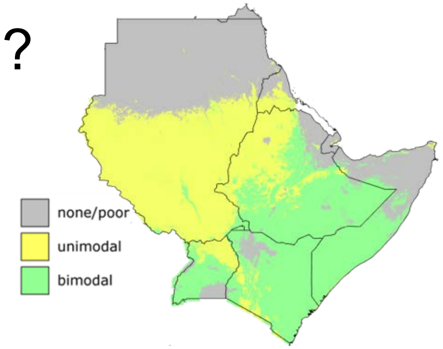
- Phenological analysis provides better seasonal definitions
  - Forage scarcity index relates to when forage is developing
  - Large spatial variability across study area
  - Prerequisite for moving to new areas (KLIP)

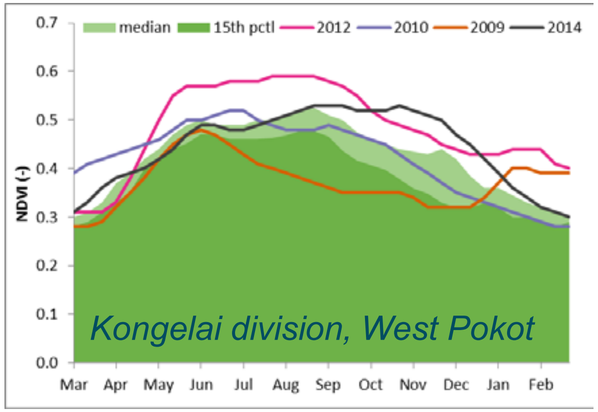
- Insurance payments can be made 1-3 month earlier
  - considering also season predictability (overall similar payout)
  - accounting for NDVI filtering important (rainy season likely more clouds)
  - location-dependent

- Earlier payment may allow protection livestock
  - purchase of forage, water, medicines OR movement livestock

CHALLENGES (1/4)

- Spatial: where is seasonal index effective?
  - Units that are generally very dry
  - Stable season start/end?
  - Upscaling (KLIP)

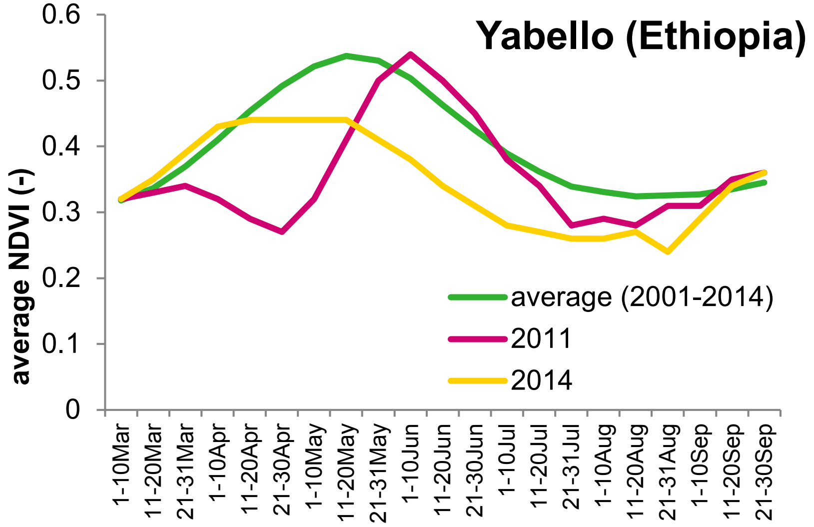




- Spatial: can we improve spatial aggregation of NDVI within units?
  - Ideally focus on key forage areas only
  - Changing vegetation not relating to drought:
    - *Prosopis juliflora*
    - Expansion agriculture / dwellings

CHALLENGES (2/4)

- Temporal: Need to incorporate greenness distribution within season?
  - within-season distribution: importance on livestock?
  - effect of previous season on livestock mortality
  - importance = location-dependent (or livestock-type dependent)?



CHALLENGES (3/4)

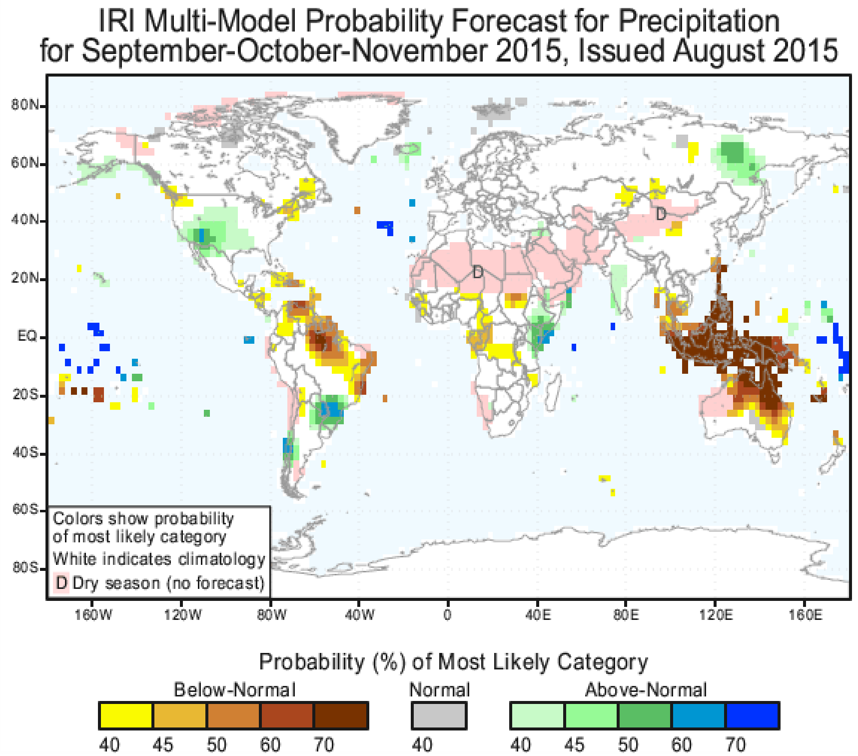
- How to assess insurance quality / basis risk ?
  - IBLI “disconnected” from livestock mortality
  - Primary productivity forage → forage scarcity index
    - Requires biomass measurements (Roumigué et al 2015)
    - Complex savanna environment (+ large/remote):
      - Grasses: cows / sheep
      - Shrubs: goats
      - Trees: camels

  - Follow up options:
    - plot biomass / time lapse photography / crowdsourcing
  - Alternatives:
    - Drought measures: drought recall exercises / weather stations / tree rings
    - Drought outcomes: livestock mortality, milk production, MUAC

CHALLENGES (4/4)

- Pre-triggering: can we pay out partially even earlier if first part season performs really bad? (other predictability analysis)

- Seasonal forecasts: where are they accurate and how could this affect:
  - adverse selection
  - premium prices



DROUGHT MONITORING BASICS: FAO E-LEARNING

- "*Remotely Sensed Information for Crop Monitoring and Food Security – Techniques and methods for arid and semi-arid areas*"
- http://www.fao.org/elearning/#/elc/en/course/FRS

1 Introduction
2 Remote Sensing Data for Crop Monitoring
3 Data Sources and Products

4 Rainfall and NDVI Anomaly Maps
5 Rainfall and NDVI Seasonal Graphs
6 Crop Status Analysis Throughout the Crop Season

7 Introduction to Yield Forecast
8 Communicating Results
9 Data Management of Remote Sensing Images
10 Required Software Functionality