Towards a spatially distributed concept for cotton growth modeling by coupling the APSIM model with optical remote sensing data

Liu Guilin, Sebastian Mader, Mandy Maas, Joachim Hill
Environmental Remote Sensing and Geoinformatics
Trier University, 54286 Trier, http://www.feut.de

LU, Agricultural Systems, Crop Water Requirements

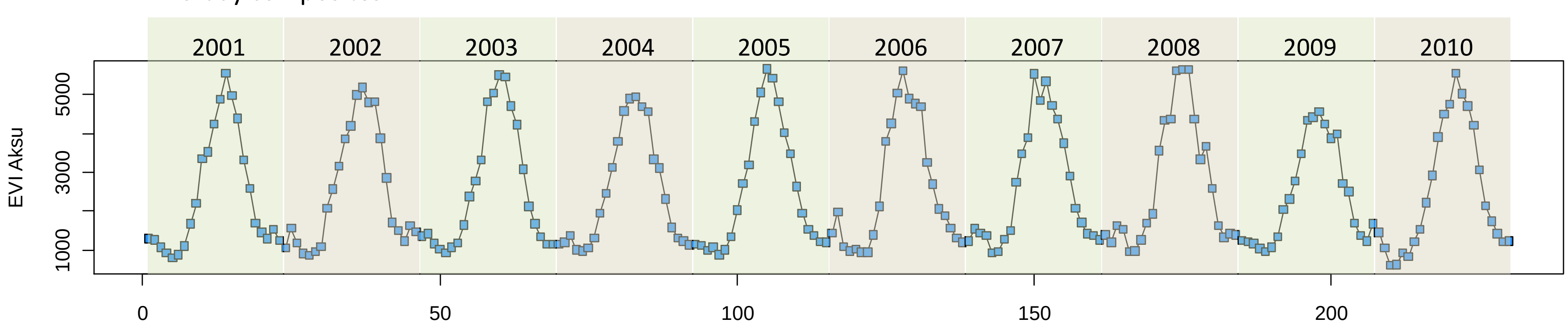
WB 3: Sustainable Water and Landuse Management in the Tarim Basin

- WP 3.1: Water requirement and water quality on the plot scale (0.1 km²)
- WP 3.2: Hydrology, salinity and biomass production on the local scale (10 km²)
- WP 3.3: Upscaling to the regional scale (200 km²)
- WP 3.4: Modeling of the water balance along the Tarim River (1000 km)

Prime Research Topics:

- Mapping Land Use Dynamics, Characterize Land Use Systems — **MODIS EVI Time Series**
- [Characterize Regional Evaporation Rates (SEBAL)] — **MODIS Refl./Emissive**
- Optimizing Crop Management: Assimilation of RS-derived Observation into a Cotton Growth Model — **Landsat-7/-8, RapidEye, Chinese Satellites (HJ-1A CCD, HJ-1B CCD, GF-1 CCD)**

16-day composites

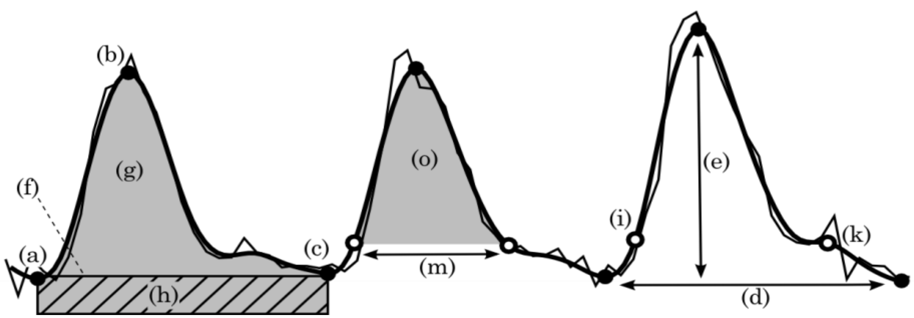


Phenological Parameters:

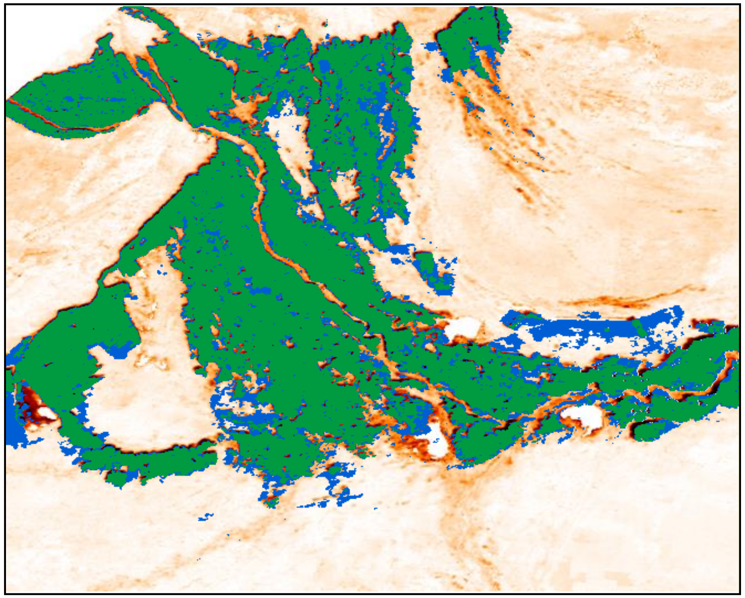
(a),(c),(b),(m): location/value of annual minima, peak, period between minima

(i),(k),(e),(f),(d): time/value of start/end of growing season, amplitude, base level, length of growing season

(g),(h),(o): integrals: total/minimum to minimum integral („total biomass“), latent integral, seasonal integral



2001: Magnitude of Annual Cycle

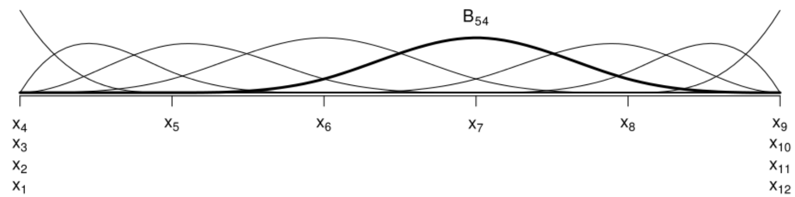


Agricultural Area (2001) : 545831.3 ha
(2010) : 712106.3 ha

Increase by 166275 ha = 30 %

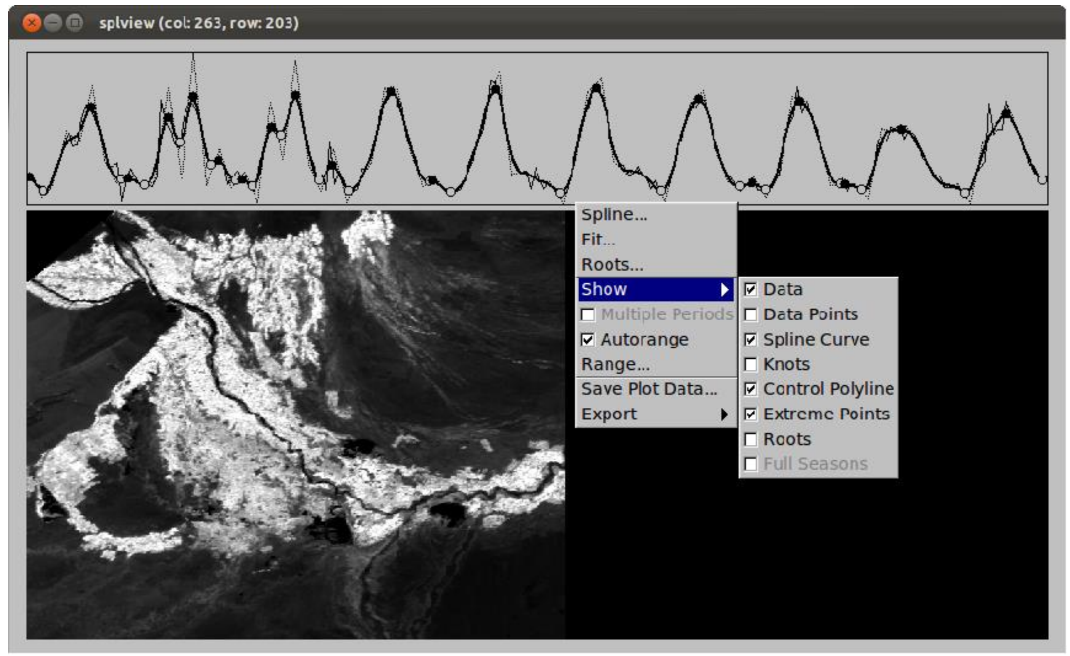
Feike, T., Mamitimin, Y., Li, L., & Doluschitz, R. (2015). Development of agricultural land and water use and its driving forces along the Aksu and Tarim River, P.R. China. *Environmental Earth Sciences, 73*, 517-531

Spline-based Modelling of Phenological Time Series (e.g. MODIS EVI)



Clamped B-spline basis, 5 polynomial pieces

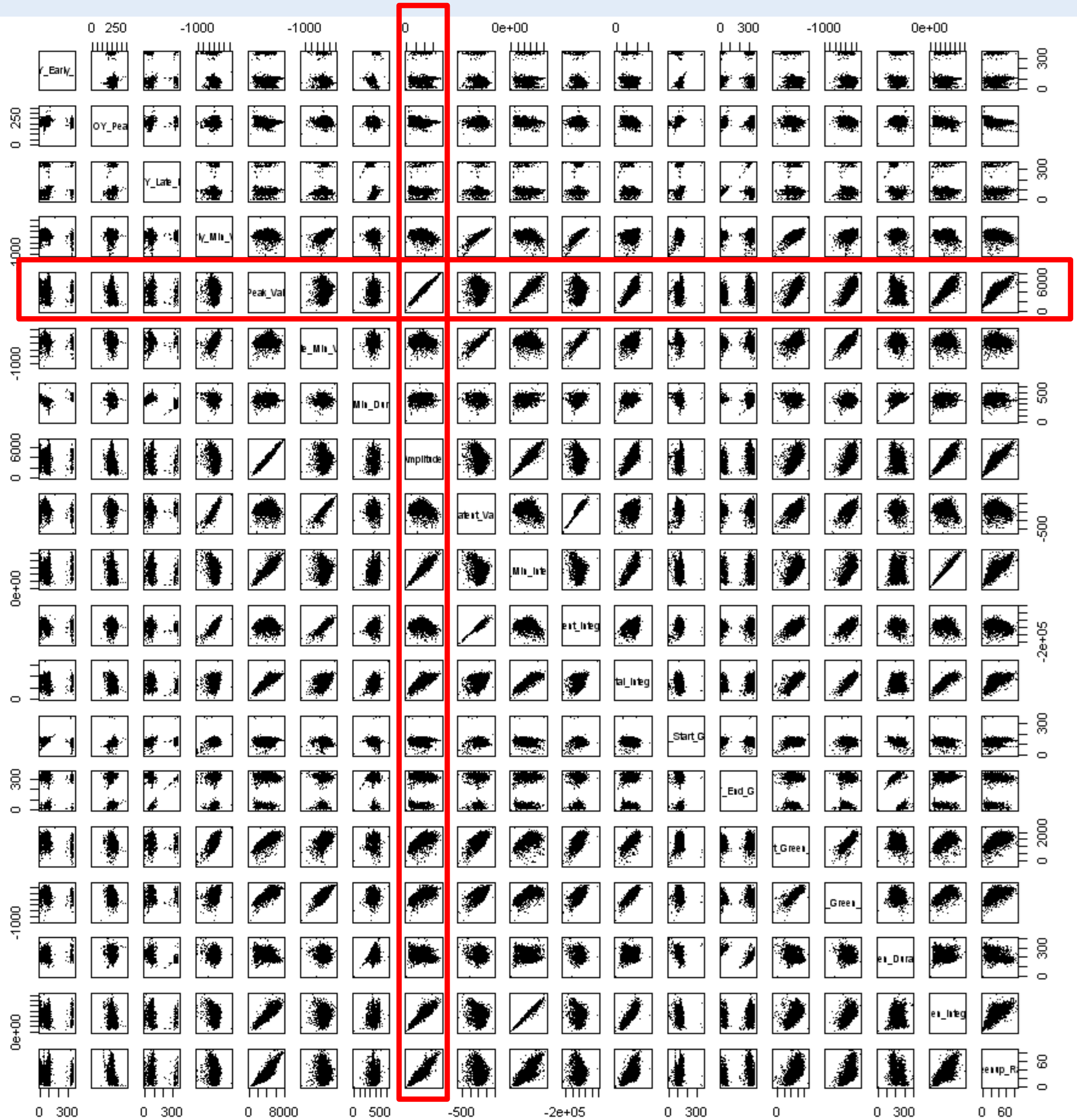
$$f(t) = \sum_{j=1}^{m} c_j B_{j,k}(t)$$



$$B_{j,1}(t) = \begin{cases} 1 & \text{if } x_j \le t < x_{j+1} \\ 0 & \text{otherwise} \end{cases}$$

$$B_{j,k}(t) = \frac{t - x_j}{x_{j+k-1} - x_j} B_{j,k-1}(t) + \frac{x_{j+k} - t}{x_{j+k} - x_{j+1}} B_{j+1,k-1}(t)$$

Mader, S. (2012): A Framework for the Phenological Analysis of Hypertemporal Remote Sensing Data Based on Polynomial Spline Models. Dissertation, Universität Trier.

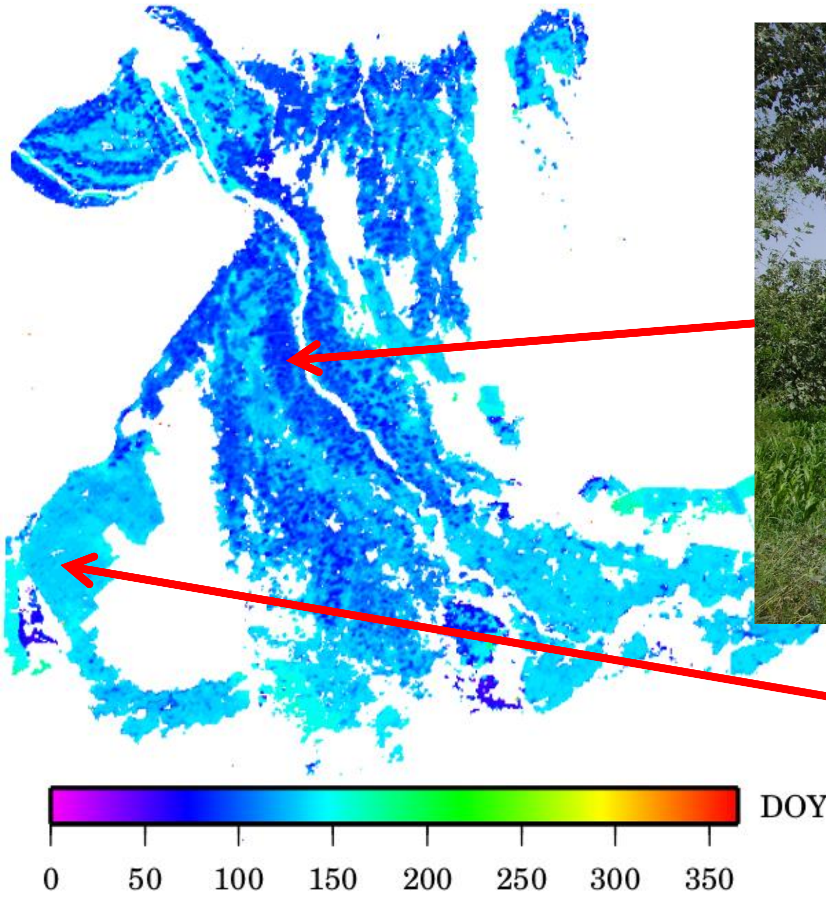


Not every phenological parameter is indicative and meaningful in a given application.l

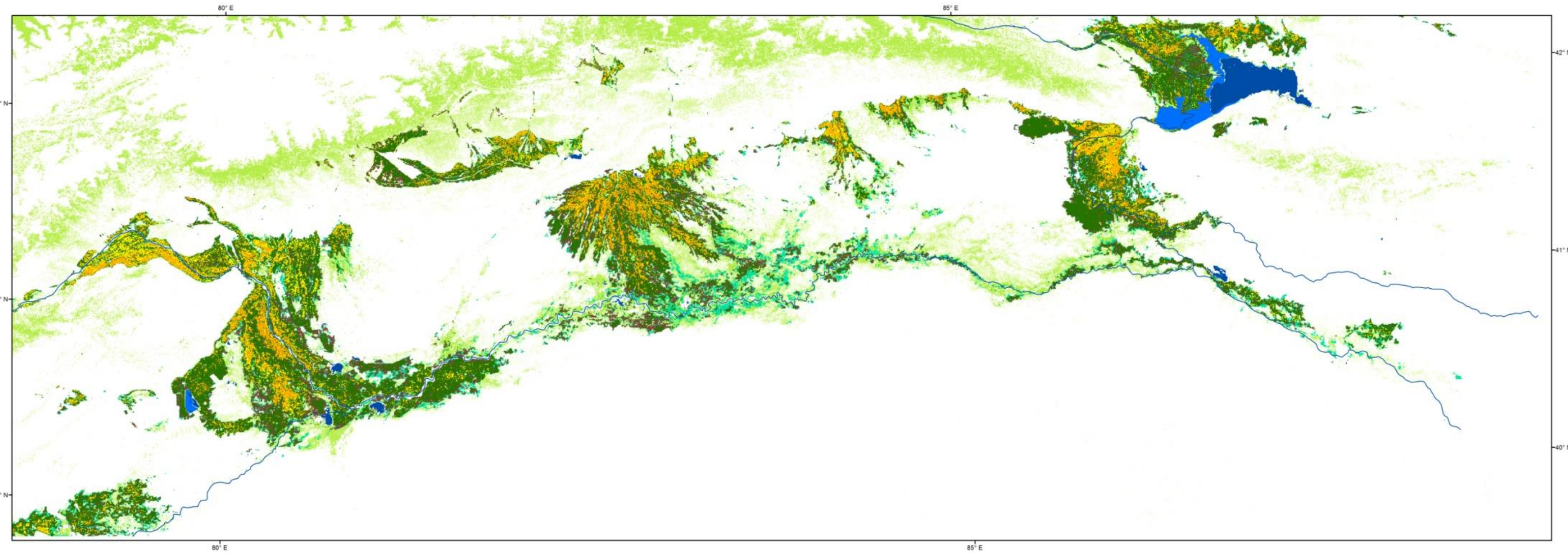
Frequently there are high correlations (e.g. annual peak value and amplitude)

Highly correlated parameters are redundant and therefore not used in the analysis.

Example:
Start of Growing Season (2005)



Agricultural Land Use Systems (based on Classifying Phenological Markers from MODIS EVI)



Land use systems

- Small scale mixed cropping systems (tree crops with maize, wheat; occasionally cotton)
- Mixed cropping systems (primary cotton, associated with wheat and maize)
- Large scale farming (cotton, high productivity)
- Large scale farming (cotton, low productivity)
- Marginal agriculture, mixed with semi-natural vegetation systems

Semi-natural vegetation Proportional cover [%]

100
75
50
25
0

Universität Trier Environmental Remote Sensing & Geoinformatics

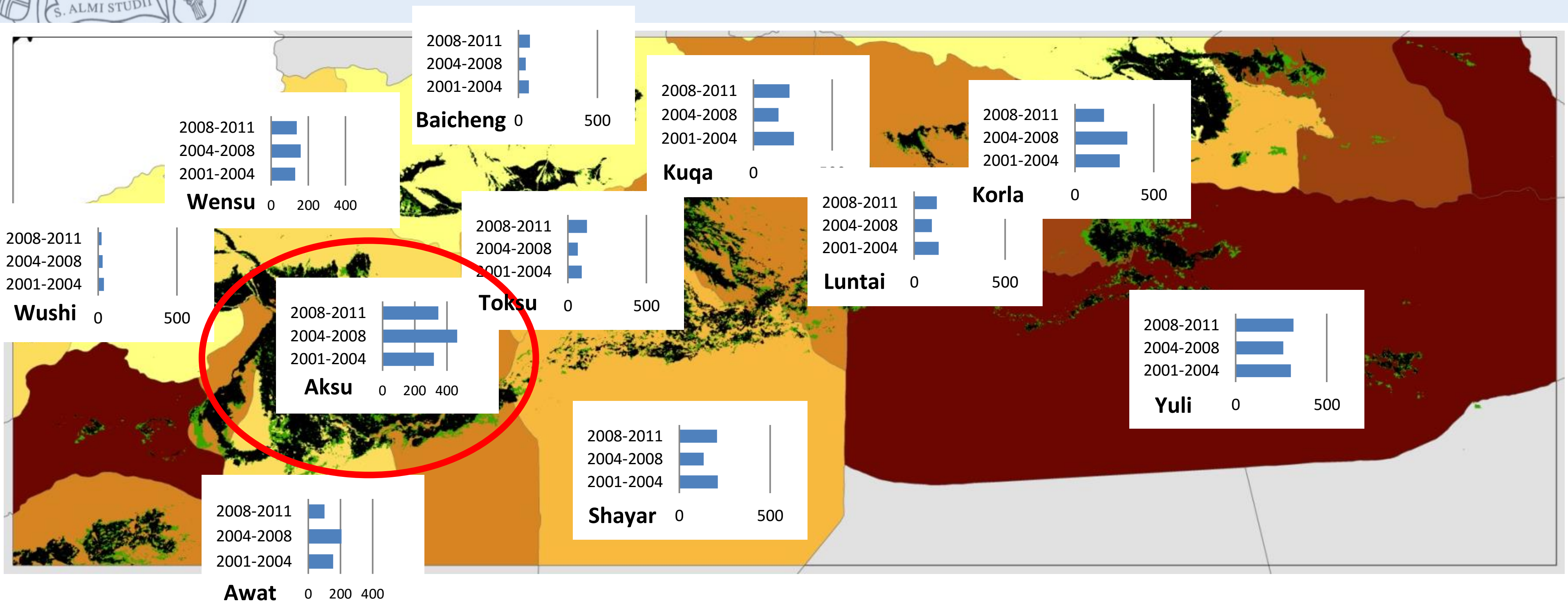
0 25 50 100 km

Data sources:

MODIS EVI (MOD13Q1 product, collection 5), obtained through the online Data Pool at the NASA Land Processes Distributed Active Archive Center (LP DAAC), USGS/Earth Resources Observation and Science (EROS) Center, Sioux Falls, SD, USA

GSHHS/WDBII databases (Wessel, P. / Smith, W.H.F. (1996): A global, self-consistent, hierarchical, high-resolution shoreline database. J. Geophys. Res., 101(B4): 8741-8743)

Projection: UTM Zone 44 N
Datum: WGS 84



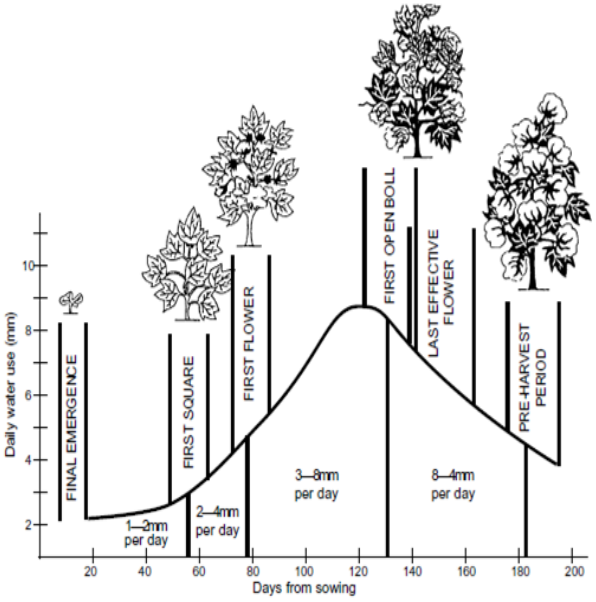
Change in Productive Cropland in km² (2001-2004, 2004-2008, 2008-2011)

	Aksu	Awat	Baicheng	Kalpin	Kuqa	Shayar	Toksu	Wensu	Wushi	Bohu	Hejing	Hoxud	Korla	Luntai	Yanqi Hui	Yuli	Bachu	Akqi	Toksun
2001-2004	319.75	153.55	65.37	20.38	257.61	212.38	88.39	129.57	36.75	45.23	53.69	80.01	283.73	134.63	27.19	302.82	114.19	2.31	3.69
2004-2008	464.07	206.16	45.49	30.75	159.44	134.75	63.38	159.37	28.25	39.42	27.44	98.32	332.85	98.26	11.44	260.75	149.44	1.50	10.31
2008-2011	346.50	101.43	71.87	33.81	228.18	207.63	121.27	137.00	21.19	48.48	34.13	81.51	185.30	124.26	15.57	317.88	109.32	5.31	14.69

Source: MODIS EVI Phenological Metrics (Annual Biomass Integral) [© Mader, Maas, Hill – ERSG 2012]

Cotton - 棉花

- Major Cash Crop (Giese et al., 2005; Feike et al., 2015)
- High Water Demand, Potentially High Water Contamination (Salinization, poor Drainage)
- Reclamation of Marginal Land
- Long-Term Sustainability ? / Optimization Potential ?

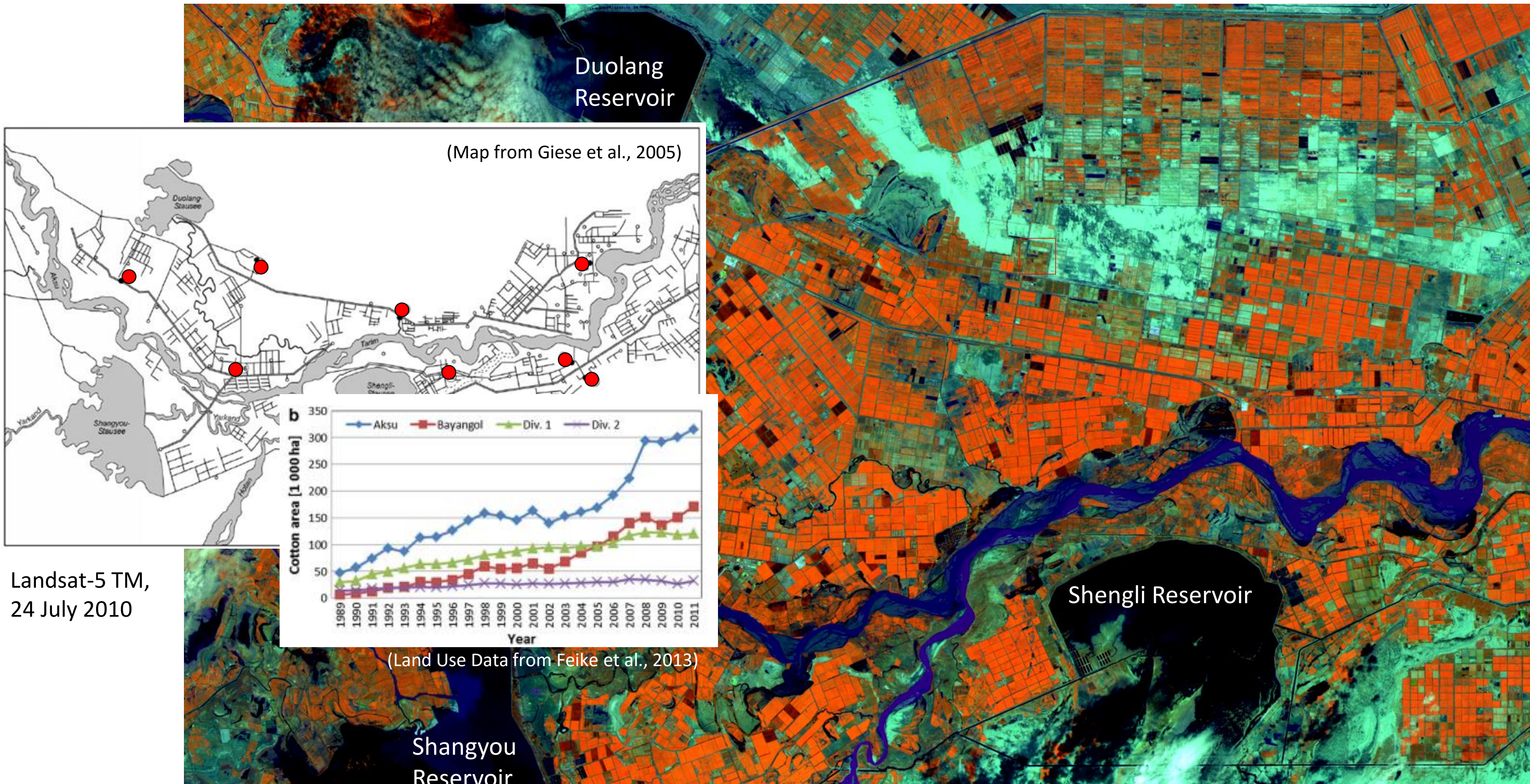


Australian Cotton Cooperative Research Centre, 2002, **Australian Dryland Cotton. Production Guide**, 3rd edition, Cotton Research & Development Corporation, 2 Lloyd Street, Narrabri NSW (Australia)

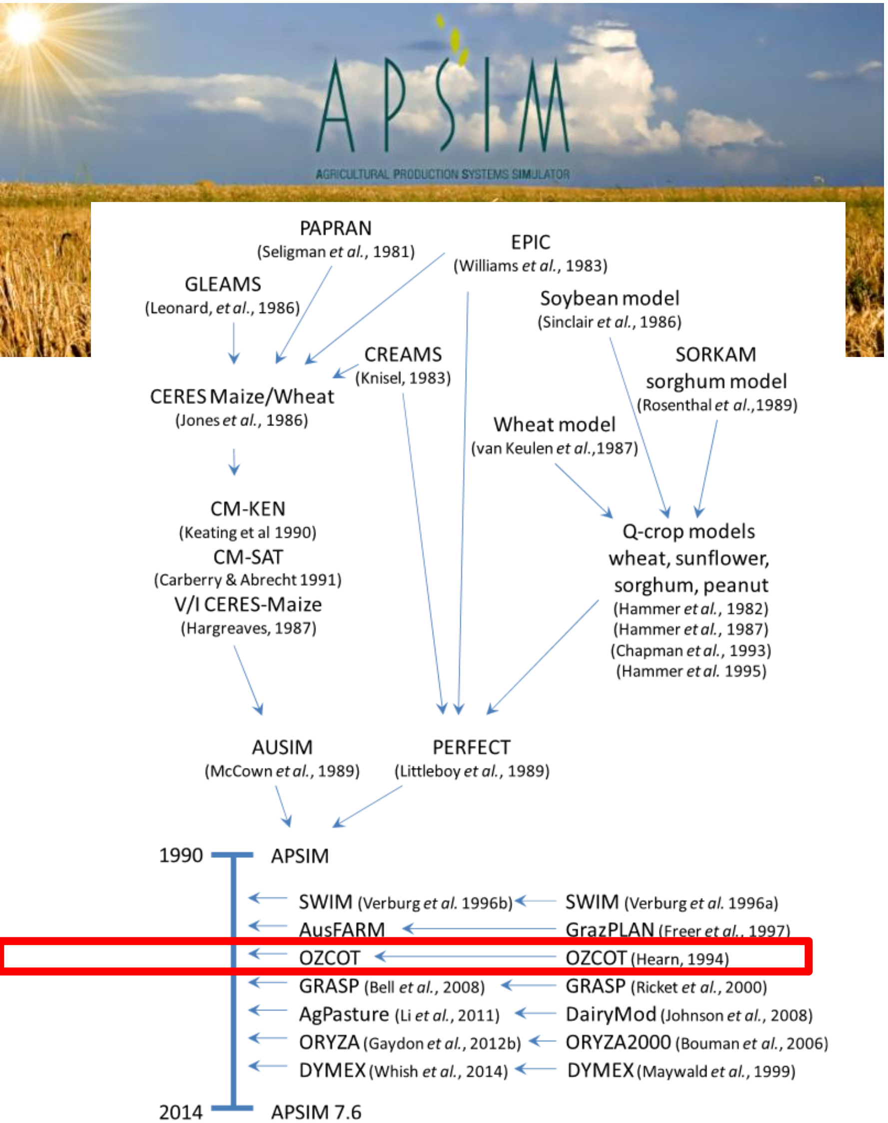
Major growth stages of cotton

Land Reclamation & Sustainability

Confluence of Aksu, Yarkand and Hotan, forming the Tarim River.
State Farms of Division 1

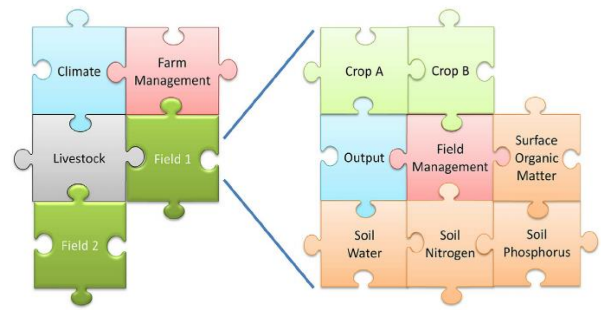


Landsat-5 TM,
24 July 2010



APSIM (**A**gricultural **P**roduction systems si**M**ulator)

an unincorporated joint venture between the Commonwealth Scientific and Industrial Research Organisation (CSIRO), the State of Queensland, through its Department of Agriculture, Fisheries and Forestry (DAFF) and The University of Queensland (UQ).



*"...u et al., 2013b). A similar arrangement provides APSIM users access to the OZCOT cotton model (**Hearn, 1994**). APSIM is no longer just a cropping systems model but can also simulate the growth of a range of p..."*

APSIM – Evolution towards a new generation of agricultural systems simulation

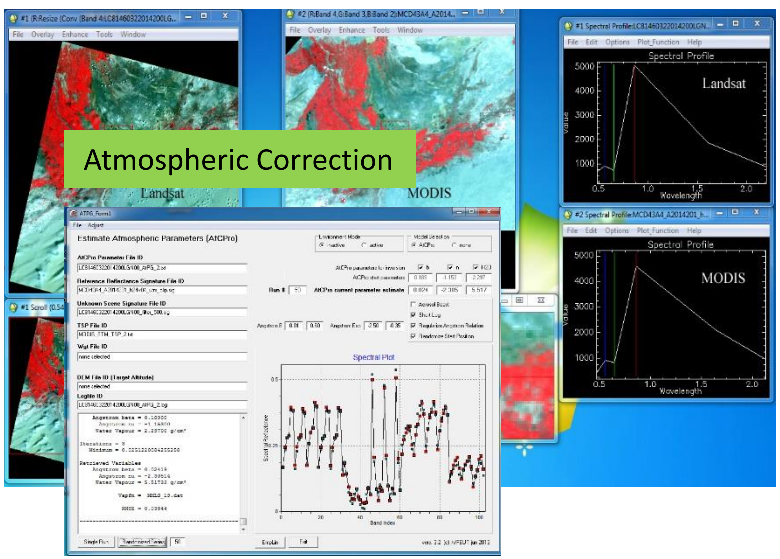
Holzworth, D. P., Huth, N. I., Zurcher, E. J., Herrmann, N. I., McLean, G., Chenu, K., ... & Keating, B. A. (2014). APSIM – evolution towards a new generation of agricultural systems simulation. *Environmental Modelling & Software*, *62*, 327-350.

Hearn, A. B. (1994). OZCOT: A simulation model for cotton crop management. *Agricultural Systems*, *44*(3), 257-299.

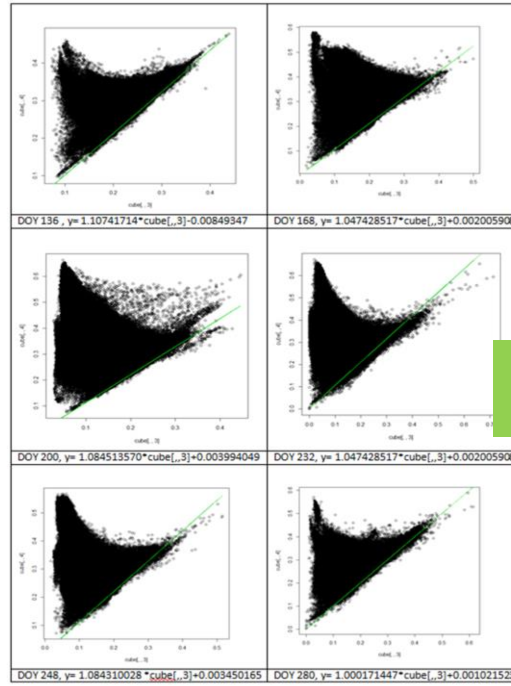
Field Work 2014 (Plant Height, LAI)

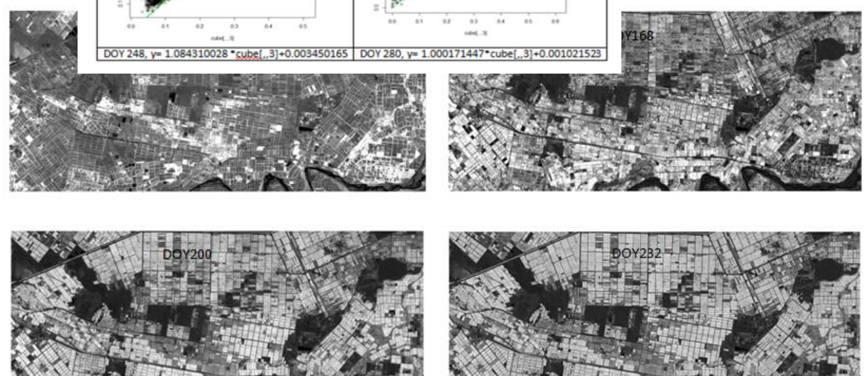
Fig.2 Field works during three major cotton growth stages

Atmospheric Correction

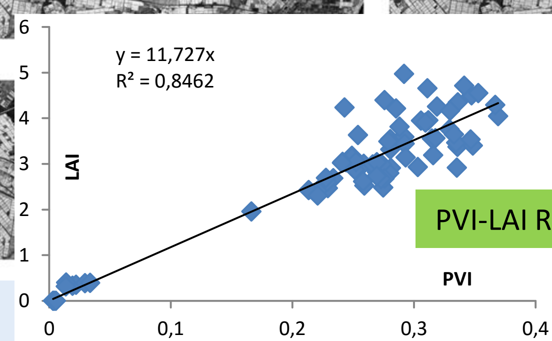


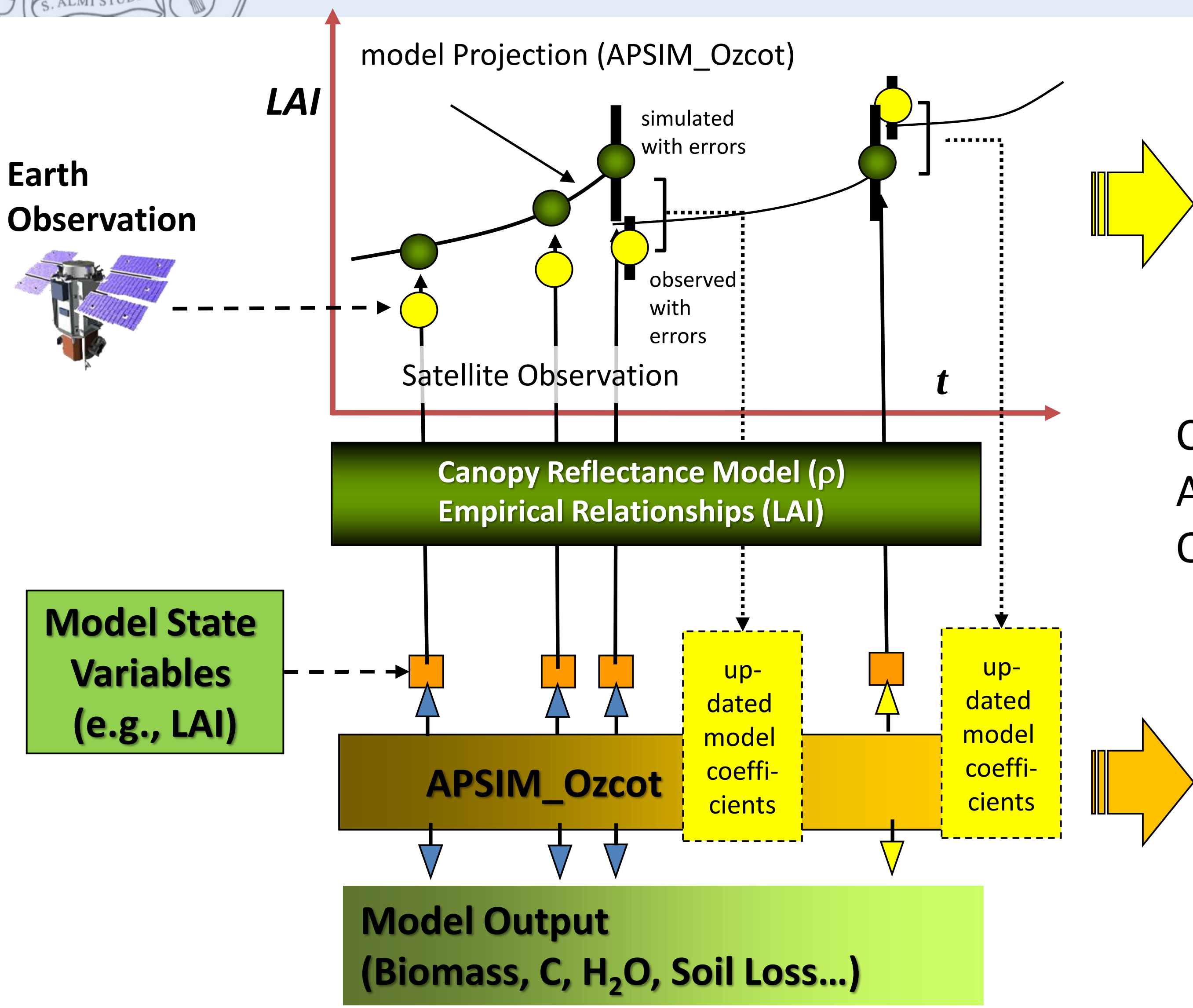
PVI (soil-corrected VI) Calculation





PVI-LAI Relationship

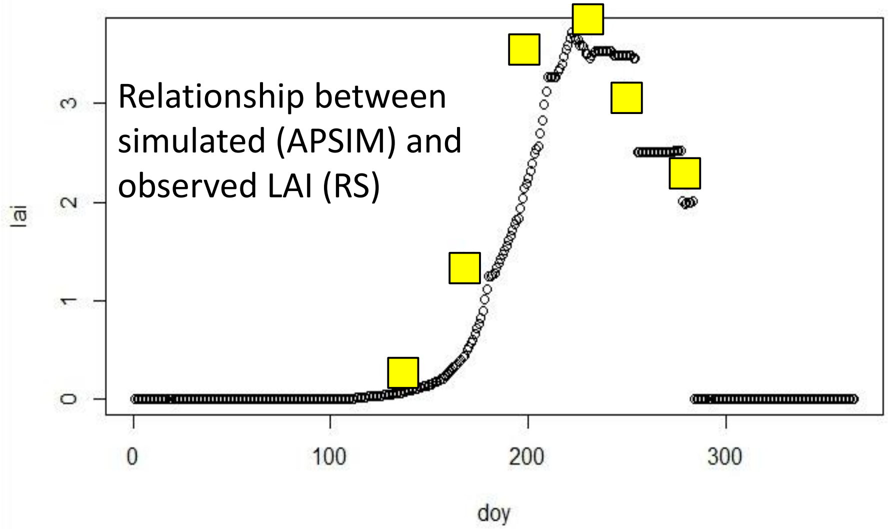


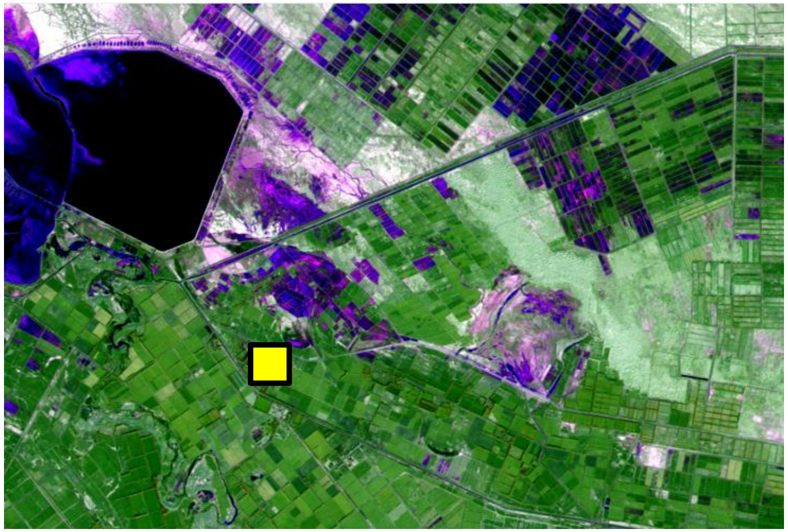


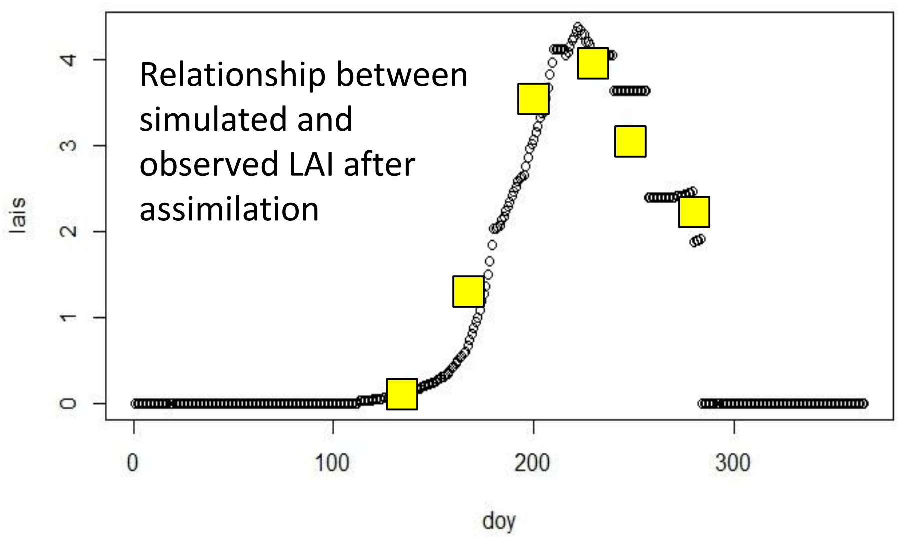
Model adjustments: Indicate deviations from standard conditions

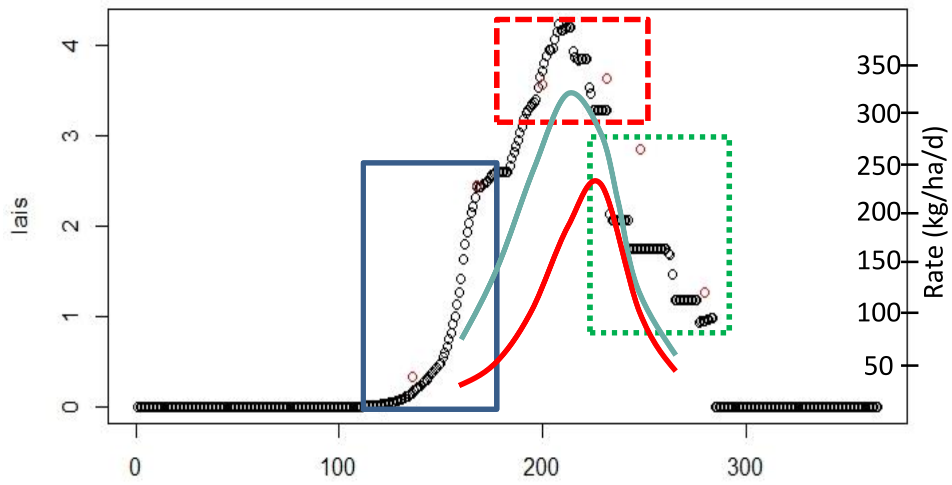
Crop Growth Models: Assimilation of Satellite Observations…

Sequentially optimized yield estimates





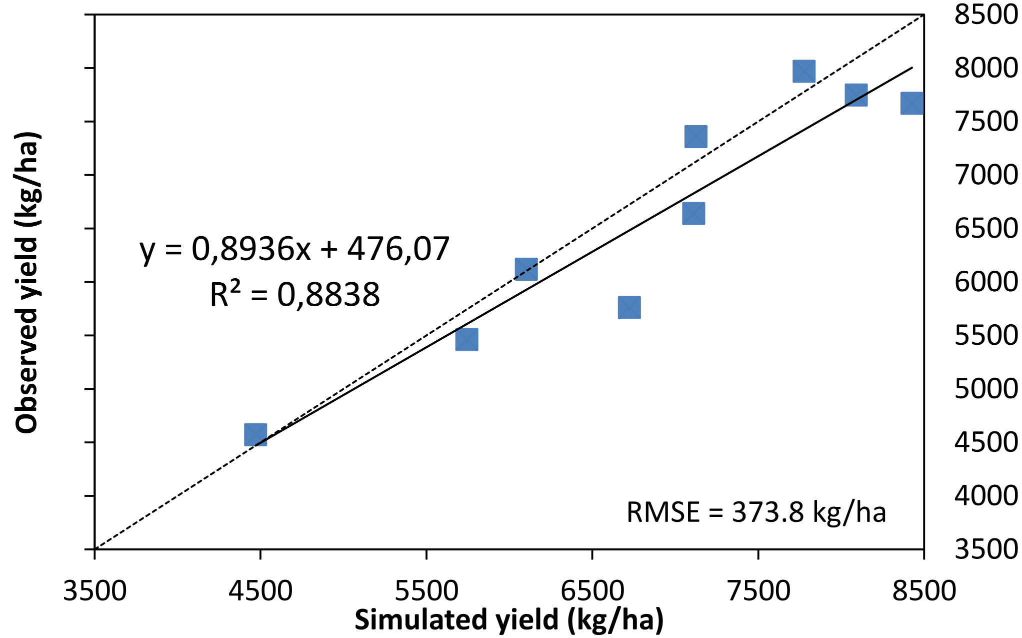




Vegetative / Reproductive Growth

Assimilating Satellite Observations (LAI) into APSIM/Ozcot:

Modelled vs. Measured Yield (2014):



Yield data provided by H. Othmanli (U. Hohenheim)

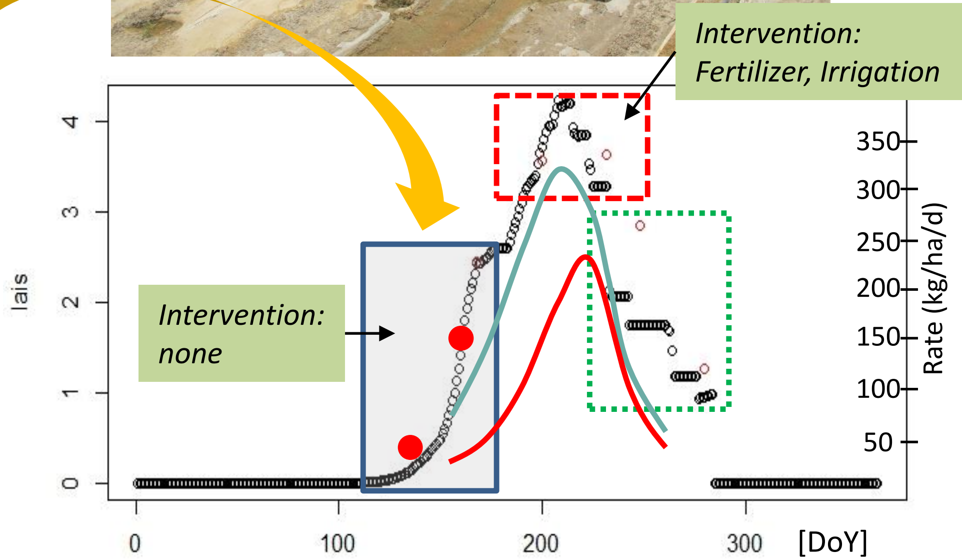
APSIM/Ozcot Assimilation Strategy

- Growth Phase 1: Emergence -> Squaring
- Management = sowing (incl. initial fertilizer)
- Climatic Conditions = homogeneous
- Soil Conditions = homogeneous

- Assimilation of two Satellite Observations (doy 136 and doy 168)

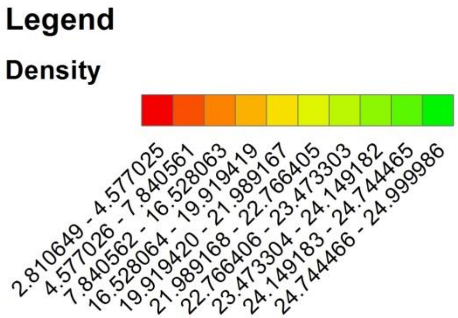
Differences between early LAI development (i.e. forced adaptation of model parameters*):

Indicator for differences in local growth conditions (salinized soils, lack of water and/or nutrients

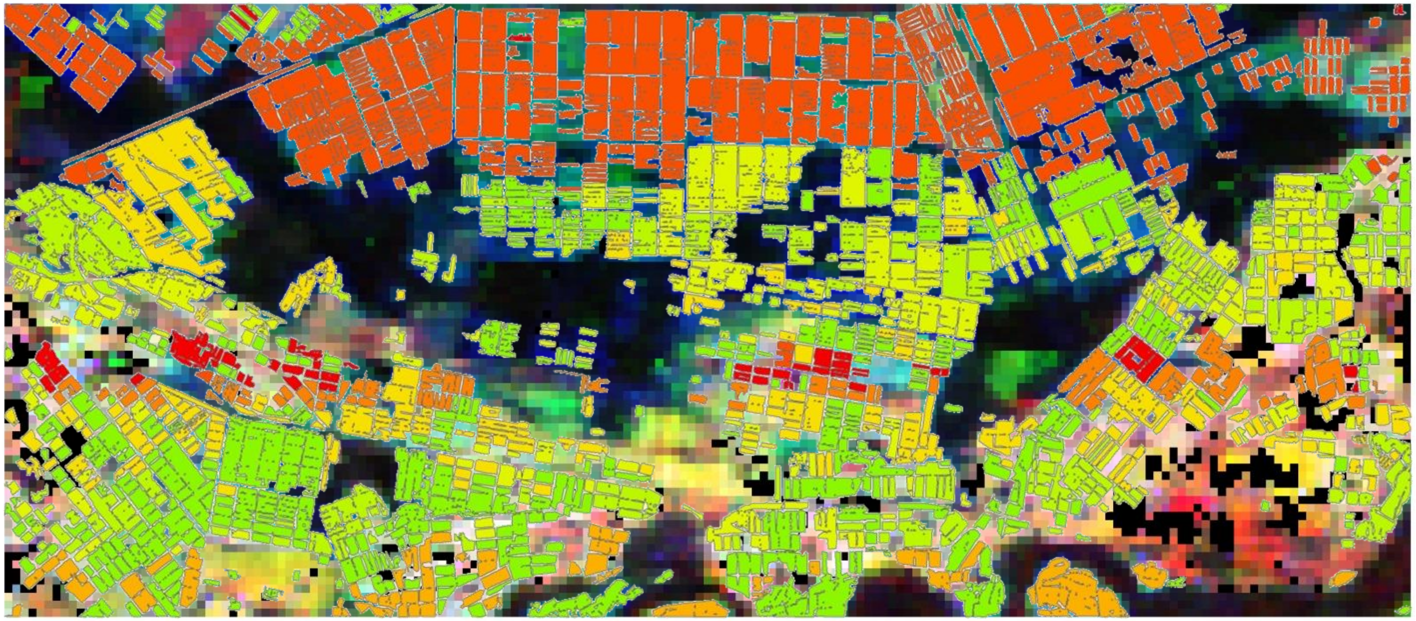


Vegetative / Reproductive Growth

*) plant density, RLAI

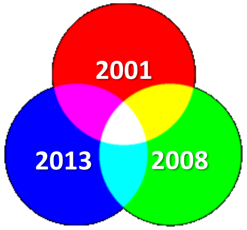


Spatial Distribution of „Plant Density“
adjusted by APSIM to optimally match satellite observations of LAI



Legend

MODIS EVI „Magnitude“



N

Land Use Change Dynamics
based on Phenological Descriptors
derived from MODIS EVI Time Series

Conclusions …

- Agricultural land in the Aksu-Tarim Region more than doubled between 1989 and 2011 (c.f. Feike et al., 2015)
- Phenological metrics derived from continuous satellite observation provides reliable area estimates of agricultural land
- Expansion of cotton production is largely based on reclaiming unused land of limited productivity
- Coupling crop growth models (APSIM) with satellite observations provides improved yield estimates for cotton
- Model adjustments resulting from the assimilation of satellite observations reveal land degradation hot spots and management shortcomings