Retrieval of coarse-resolution leaf area index over the Republic of Kazakhstan using NOAA AVHRR satellite data and ground measurements

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Outline

- General Research Goals in Central Asia and Motivation
- Meaning / definition of LAI
- Accuracy of Remote Sensing Inputs like NDVI, FAPAR or LAI
- Our methods to measure LAI in the field
- Information about test sites in Kazakhstan
- Method for deriving the National LAI-Dataset of Kazakhstan
- Comparison of LAI-Dataset with LAI-field data and other global LAI-Datasets
- Summary and Outlook

Research Goals in Central Asia

1. Investigation of climate and human impacts on vegetation
2. Deriving biophysical variables such as: LAI, fPAR etc.
3. Biomass (grass / crop) production with RS and ground truth data (Review and development of models, e.g. Göttingen-BioStar-model; reporting to AgMIP)
4. Modeling of ecosystem production (NPP, GPP, NEP); new Software BioSTAR
5. CO_2-Sequestration of grassland

Definition of leaf area index (LAI)

Leaf Area Index (LAI) is a dimensionless quantity that characterizes plant canopies. It is defined as the one-sided green leaf area per unit ground surface area (*LAI = leaf area / ground area, m^2 / m^2*) in broadleaf canopies. In conifers, three different definitions for LAI have been used:

- Half of the total needle surface area per unit ground surface area
- Projected (or one-sided, in accordance the definition for broadleaf canopies) needle area per unit ground area
- Total needle surface area per unit ground area

“Usually, the Leaf area index (LAI) is defined as one half the total leaf area per unit ground surface area projected on the local horizontal area“ *

***** Source: I. Jonckheere, S. Fleck, K. Nackaerts et al., “Review of methods for in situ leaf area index determination Part I. Theories, sensors and hemispherical photography,” *Agricultural and Forest Meteorology*, vol. 121, no. 1-2, pp. 19–35, 2004.

Motivation for deriving long-time LAI-Products ?

There is a need for…

"Regional Land Data Products for Energy Budget and Water Cycle Trends and Processes in the future …" (Quelle: ISLSCP, 2009)

"Produce consistent research quality data sets complete with error descriptions of the Earth's energy budget and water cycle and their variability and trends on interannual to decadal time scales, and for use in climate system analysis and model development and validation."

ISLSCP: International Satellite Land-Surface Climatology Project

What can we measure ?

- **Top of the Atmosphere Radiance**
- **The Rest is inferred using "Algorithms":**
  - **Surface Albedo α**
  - **Surface Temperature T_S**
  - **F_{APAR} from NDVI**
  - **Porfile Water Vapor and Temperature**
  - **Aerosol Optical Depth**
  - **Short Wave Down**
  - **Soil Moisture? Freeze/Thaw?**
  - **Vegetation Structure (LAI, F_{APAR} , Land Cover Type)**

Results from other projects like Fife, Boreas, ISLSCP II

- **PAR can be inferred to an accuracy of 8.2 Wm^{-2}**
- **Solar insolation to an accuracy of 21.6 Wm^{-2}**
- **Surface albedo to about 3% absolute, ~15% relative**
- **Downwelling longwave radiation to about 20 Wm^{-2}**
- **Net radiation to roughly 50 Wm^{-2}**

Accuracy of Remote Sensing Inputs like NDVI, FAPAR or LAI

- **NDVI = (NIR-VIS) / (NIR+VIS)**
  - **SURFACE NIR ACCURACY ± 4% ABS**
  - **SURFACE VIS ACCURACY ± 1% ABS**
- **NDVI TO ± 5% (0.05 OUT OF 1)**
- **GLOBAL NDVI ANOMALY OF 0.01 RESULTS IN MODELED GLOBAL CARBON FLUX ANOMALY OF 2.0 Pg/yr (Schulze, 2011)**
- **LAI BELOW SATURATION VALUE OF ~3, ± 20%**

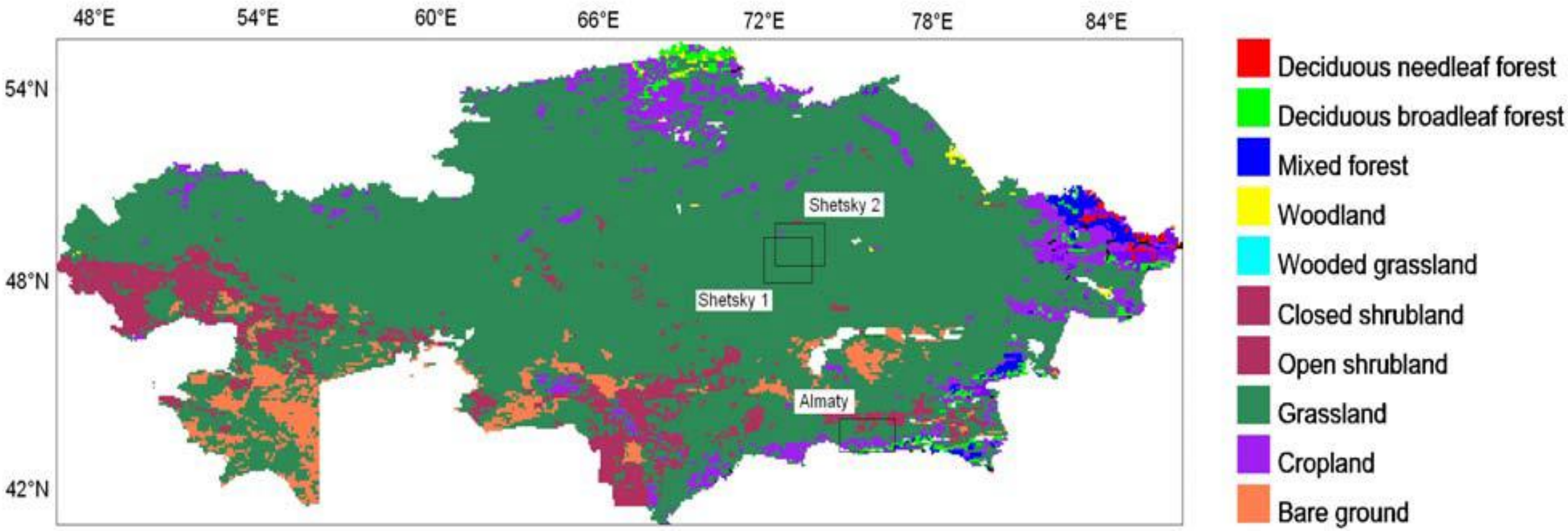
Our approach: Vegetation structure variables (LAI, fPAR)

- **LAI and fPAR were measured at 50 sample plots across the study area using gap fraction analysis of hemispherical photos.**
- **Li-Cor 2000 measurements for Lai /fPAR**
- **Destructive Method in field plots (1 m²)**

- **WinScanopy Image Acquisition instrument** developed by the Canadian firm REGENT INSTRUMENTS (http,//www.regentinstruments.com) was used to get hemispherical photos.
- The **"Can Eye"** software (INRA, France, http,//www.avignon.inra.fr/can_eye/) was used for the processing of hemispherical photographs and derivation of LAI and fPAR values**.**"Can Eye" uses a look-up-table approach which is composed of gap fraction measurements in different view zenith angles and the corresponding LAI and fPAR parameters.
- Additionally **LI-COR-2000** instrument was used to measure LAI and fPAR

Overcast sky is the best!

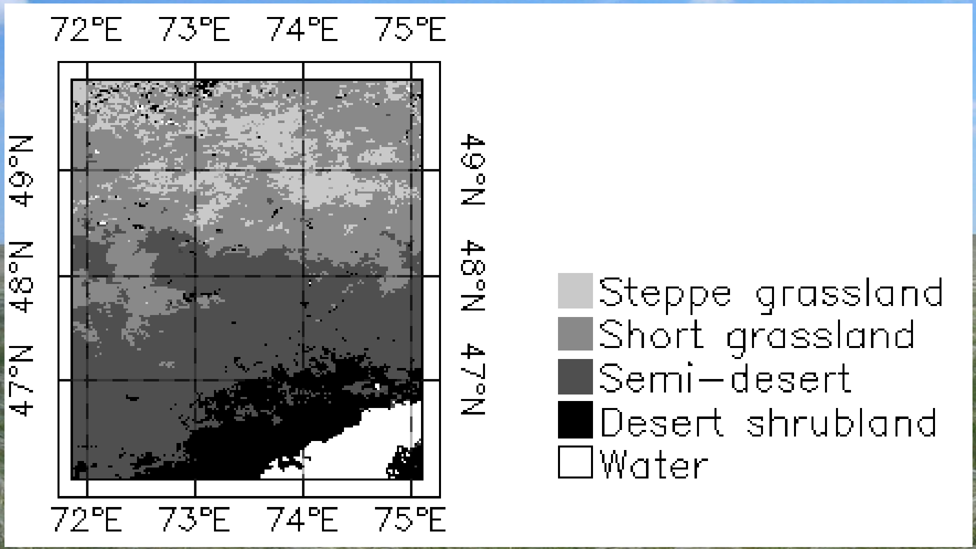
Test Sites for deriving the National LAI-Data Set



Land cover classification after AVHRR land Cover

Study Area

Land cover types



Landscape impressions

Desert

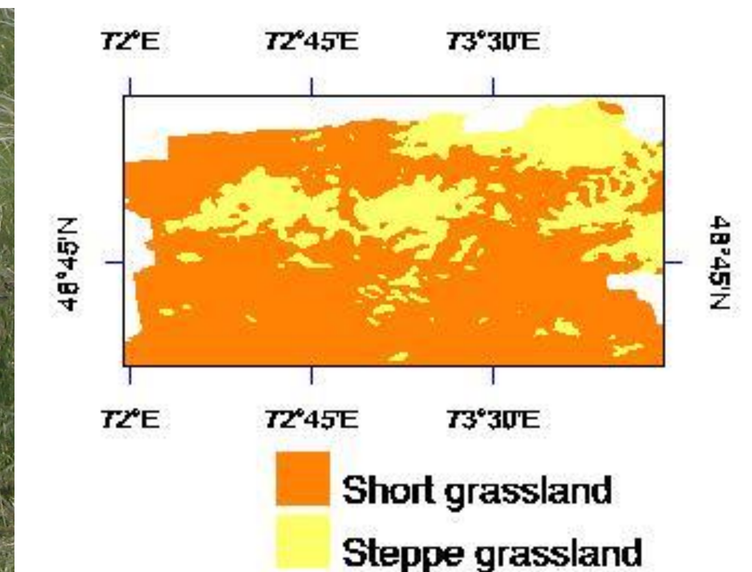
Semi-desert

Short grassland

Steppe grassland

Vegetation cover of the study area

- The **grassland** is dominated by genera ***Festuca*** and ***Stipa****.* Few euryxerophilous forbs occur; the co-dominants are dwarf shrubs of the genus ***Artemisia*** and sometimes of other genera, particularly ***Anabasis*** and ***Salsola***.
- **Species diversity** is about 12-15 species in a square metre.
- The **height of the canopy** decreases from 30-40 in the north to 15-20 in the south, while vegetation cover decreases from 50-70% to 20-30%, and even less.
- there are only two main vegetation classes, **short grassland** and **steppe grassland**. The land cover data in the study area were taken from the digital land-cover map derived from MODIS by Friedl et al. 2002 (USGS) archive centre.



Short grassland

Short grassland

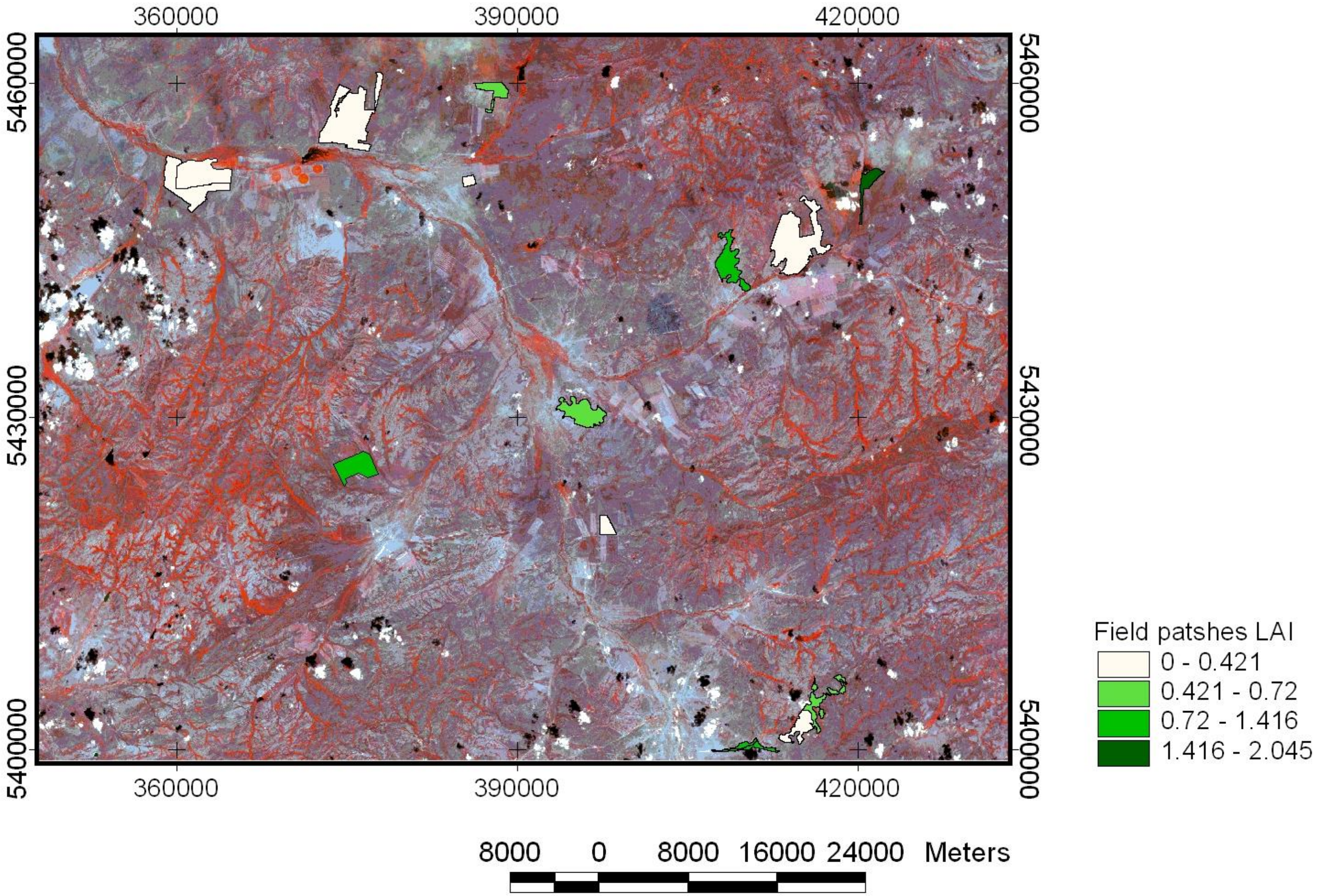
Steppe grassland

Dwarf Shrub land

LAI-Results of Field Measurements

Test Site and Number of Sampling Plots	Date	Vegetation Type	Measurement Method	LAI Range
Shetsky 1, 14 plots	June 2004	Grassland	Direct contact destructive	0.25–1.12
		Cropland		0.31–0.85
Shetsky 2, 20 plots	June 2008	Grassland	Indirect non-contact optical	0.30–1.55
		Cropland		0.21–0.75
		Shrubland		0.84–2.06
Almaty, 16 plots	June 2008	Mixed forest	Indirect non-contact optical	3.30–5.90
		Deciduous broadleaf forest		3.10–5.10
		Deciduous needleaf forest		4.35–7.24
		Woodland		2.42–4.10

Examples of Test Sites (Shetsky Region) on basis of Landsat ETM



Deduction of the National AVHRR LAI Göttingen Data Set

- Application of a *Radiative Transfer Model after Norman et al.**

$$LAI = \frac{-\ln(1 - fC)}{k(\theta)}$$

fC = fractional vegetation cover; *k*(θ) = light extinction coefficient for a solar zenith angle θ.

- Propastin, P.; Erasmi, S. A physically based approach to model LAI from MODIS 250 m data in a tropical region. *Int. J. Appl. Earth Obs. Geoinf.* **2010**, *12*, 47-59.
- *****Norman, J.M.; Campbell, S.G. Canopy structure. In *Plant Physiological Ecology. Field Methods and Instrumentation*; Pearcy, R., Ehleringer, J.R., Mooney, H.A., Rundel, P.W., Eds.; Chapman and Hall: London, UK, **1989**; pp. 301-325.

Deduction of the National AVHRR LAI Göttingen Data Set

Fractional Vegetation Cover (fC) derived from NDVI / fC relation:

$$fC = 1 - \left(\frac{NDVI_v - NDVI}{NDVI_v - NDVI_s} \right)^b$$

NDVIv : (*fC* = 1.0) und *NDVIs* : (*fC* = 0.0).

$$LAI = \frac{-\ln(1 - fC)}{k(\theta)}$$

Modeling Light Extinction Coefficient k:

$$k = \frac{G(\theta) \times \Omega(\theta)}{\cos(\theta)}$$

k for a solar zenith angle θ was calculated as a function of the canopy projection factor (G), the clumping index (Ω) and cosines of the solar zenith angle θ (using the equation after Jarvis, P.G. et al. 1983, Jones H.G. 1992)

Deduction of the National AVHRR LAI Göttingen Data Set

Modeling Light Extinction Coefficient k:

$$k = \frac{G(\theta) \times \Omega(\theta)}{\cos(\theta)}$$

clumping index

$$G(\theta) = \frac{\sqrt{x^2 \cos^2(\theta) + \sin^2(\theta)}}{x + 1.774(x + 1.182)^{-0.733}}$$

The parameter G takes the value of 0.5 for all solar elevation angles, if the leaves are distributed uniformly over the surface of a sphere. Values of G for non-uniform leaf distribution for varying solar zenith angles were calculated using the equation from Wang, Y.P.; Jarvis, G.P. Mean leaf angles for ellipsoidal inclination distribution. *Agr. Forest Meteorol.* **1988**, *43*, 319-321*:*

$$x = \begin{cases} 151.515 \dfrac{1 - 0.0107\Theta}{\Theta} & \text{if } \Theta \geq 57.4^\circ \\ 97.087 \dfrac{1 - 0.0053\Theta}{\Theta} & \text{if } \Theta < 57.4^\circ \end{cases}$$

Deduction of the National AVHRR LAI Göttingen Data Set

Modeling of canopy projection factor G:

$$G(\theta) = \frac{\sqrt{x^2 \cos^2(\theta) + \sin^2(\theta)}}{x + 1.774(x + 1.182)^{-0.733}}$$

In this equation, x is the ratio of vertical to horizontal projection of canopy elements. The value of x can be estimated using an empirical equation relating x to the canopy leaf inclination angle Θ (after: Kucharik, C.J.; Norman, J.M.; Gower, S.T. Characterization of radiation regimes in non-random forest canopies: Theory, measurements, and simplified modeling approach. *Tree Physiol.* **1998**,*19*, 695-706.

$$x = \begin{cases} 151.515 \dfrac{1 - 0.0107\Theta}{\Theta} & \text{if } \Theta \geq 57.4° \\ 97.087 \dfrac{1 - 0.0053\Theta}{\Theta} & \text{if } \Theta < 57.4° \end{cases}$$

- For spherical canopies Θ = 57.4°, for planophile canopies 0° < Θ < 57.4°, and for erectophile canopies 57.4° < Θ < 90°. For our purpose, average values of the canopy leaf inclination angle for individual vegetation types were retrieved from hemispherical photos by the Can Eye software.

Deduction of the National AVHRR LAI Göttingen Data Set

Modeling of clumping index Ω :

$$k = \frac{G(\theta) \times \Omega(\theta)}{\cos(\theta)}$$

$$\Omega(\theta) = \frac{\Omega_{max}}{1 + c \times \exp(-2.2 \times \theta^{p})}$$

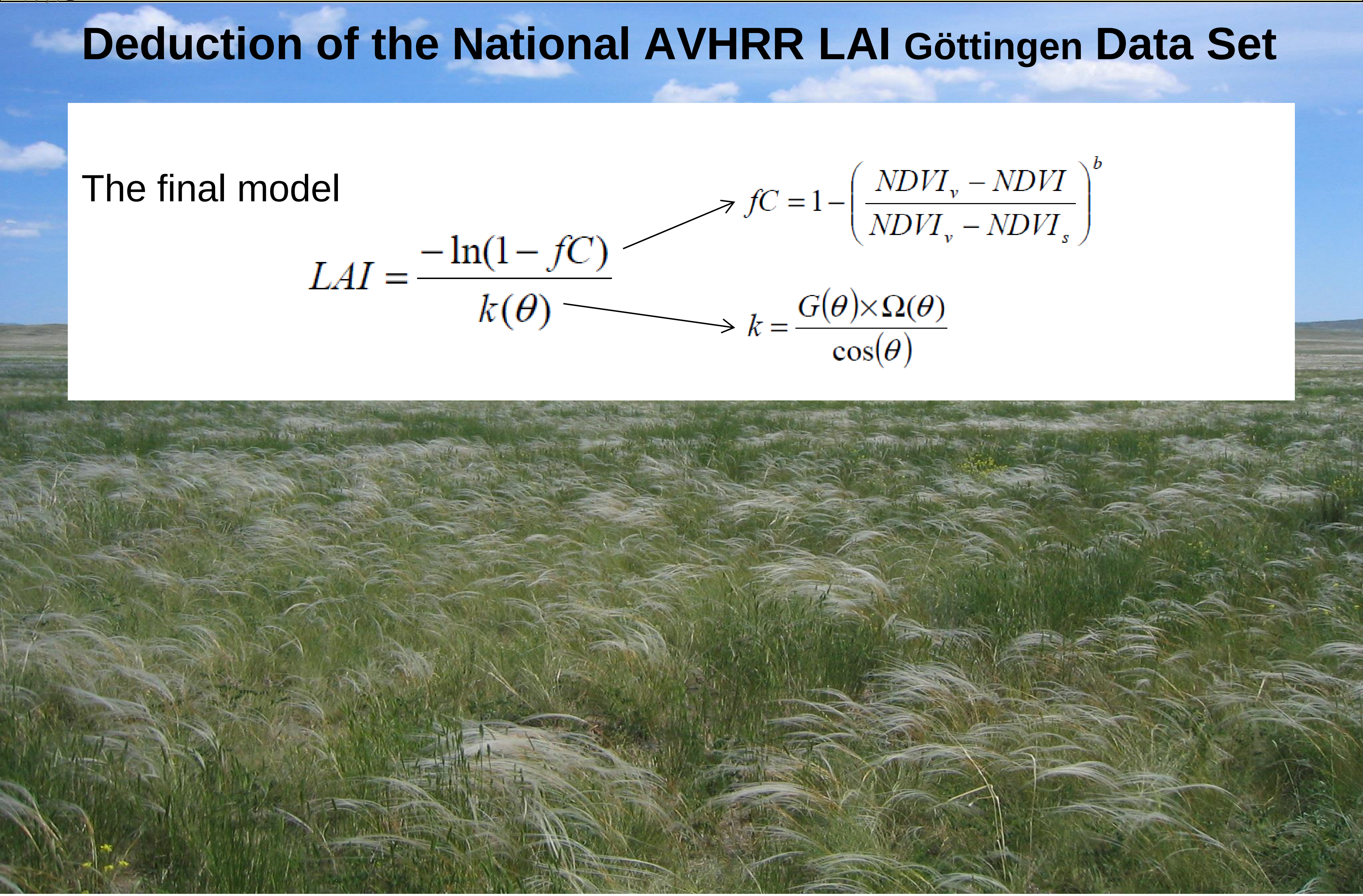
where Ωmax is the maximum clumping index for a canopy, c is a canopy-specific coefficient to be defined, and p is a function of x, given as:

$$p = \begin{cases} 1.0 & \text{if } x \leq 0.164 \\ -0.461/x + 3.8 & \text{if } 0.164 < x < 1.0 \\ 3.34 & \text{if } x \geq 1.0 \end{cases}$$

Clumping index is computed after:

- Kucharik, C.J.; Norman, J.M.; Gower, S.T. Characterization of radiation regimes in non-random forest canopies: Theory, measurements, and simplified modeling approach. *Tree Physiol.* **1998**, *19*, 695-706.

Deduction of the National AVHRR LAI Göttingen Data Set



The final model

$$LAI = \frac{-\ln(1 - fC)}{k(\theta)}$$

$$fC = 1 - \left(\frac{NDVI_v - NDVI}{NDVI_v - NDVI_s} \right)^b$$

$$k = \frac{G(\theta) \times \Omega(\theta)}{\cos(\theta)}$$

The national-wide 8-km AVHRR LAI product over the Republic of Kazakhstan for the period 1982–2010 was derived using the following steps:

(1) The fC model was applied to 1-month composite GIMMS NDVI images from 1982 through 2010. The input parameters NDVIs and NDVIv were obtained for each vegetation class respectively.

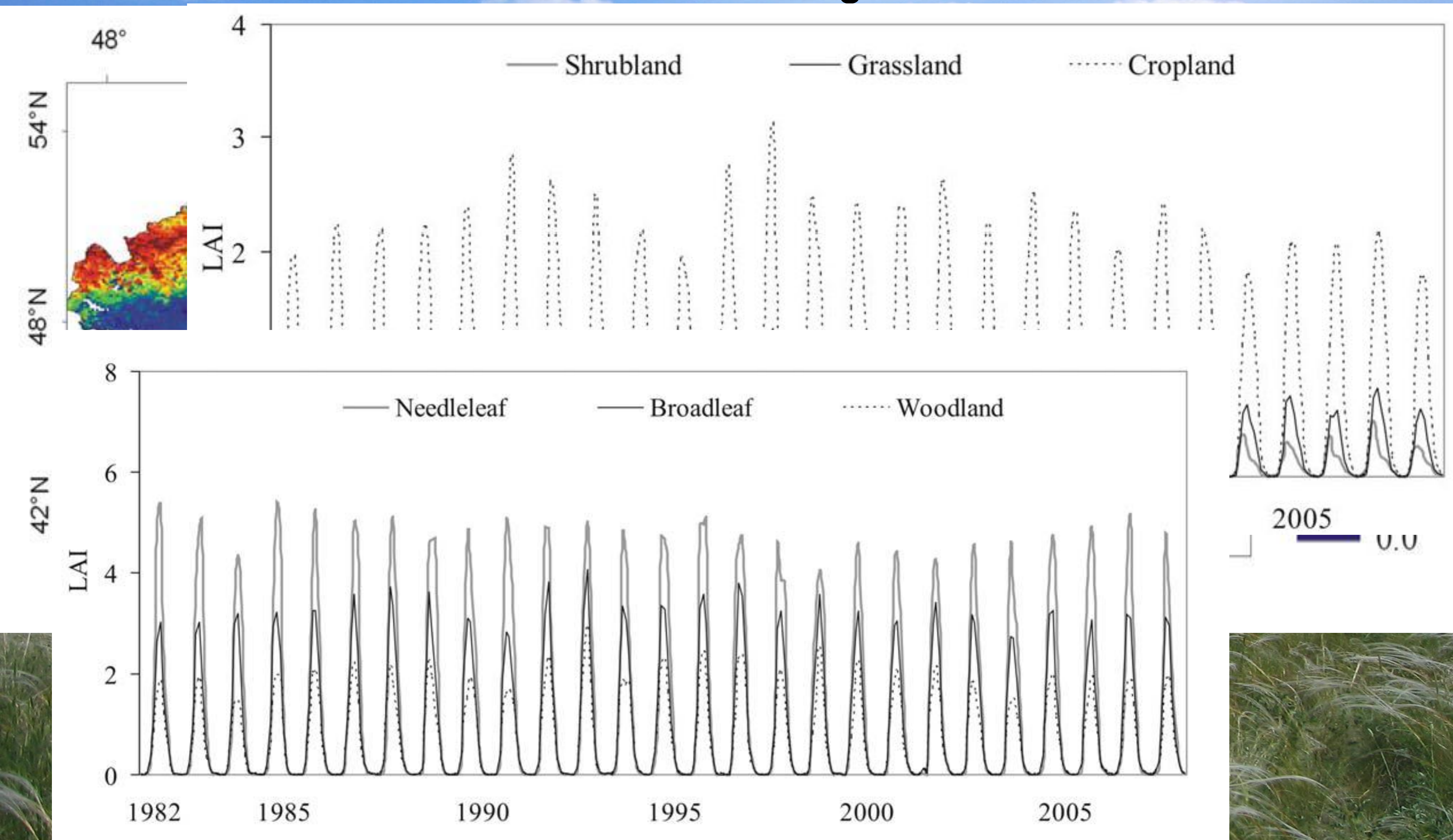
(2) Vegetation class-specific parameters x, Ωmax, c, and Θ for modeling the light extinction coefficient were determined.

- The average leaf inclination angle Θ for each individual vegetation class was modeled from hemispherical photos using the routine procedure included in the Can Eye software.
- After that, the ratio of vertical to horizontal projection of canopy elements x for individual vegetation types was calculated.
- The maximum clumping index for an individual vegetation type was assumed to be equal to the highest Ω among all test sites within this vegetation type.
- The parameter c was obtained by inverting this equation for a known value of the clumping index which was retrieved from hemispherical photography.

(3) The algorithm for the light extinction coefficient was applied at the 8-km pixel scale using a combination of vegetation class-specific input parameters, the gridded data set of mean monthly solar zenith angle, the NOAA AVHRR Land Cover and GTOPO30 elevation data sets to retrieve maps of the light extinction coefficient for the whole area of Kazakhstan.

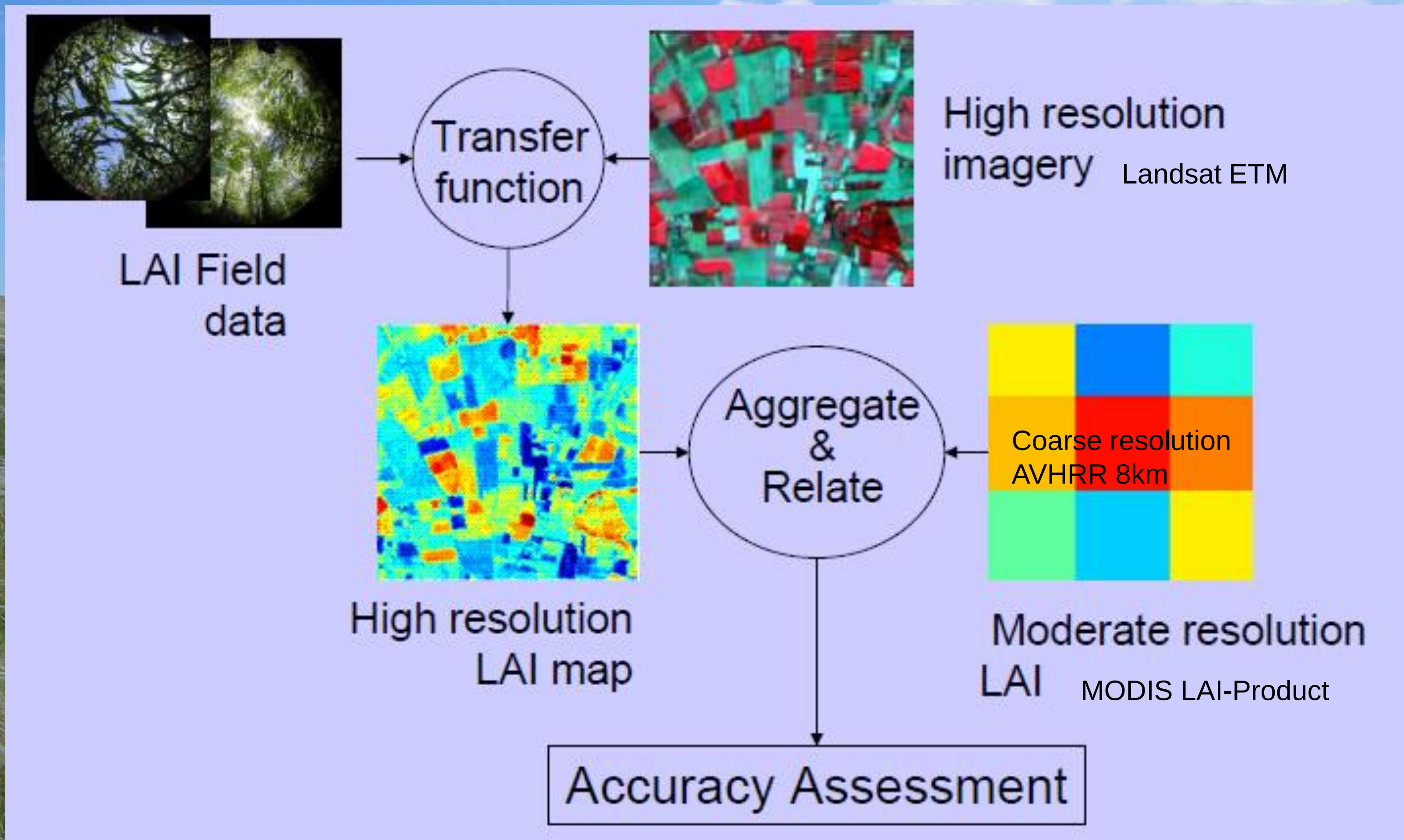
(4) LAI maps were estimated for each 1-month composite period from January 1982 through December 2010 employing the above LAI retrieval algorithm using the data sets produced by the processing steps 1 and 3.

AVHRR LAI CGRS Göttingen June 2008



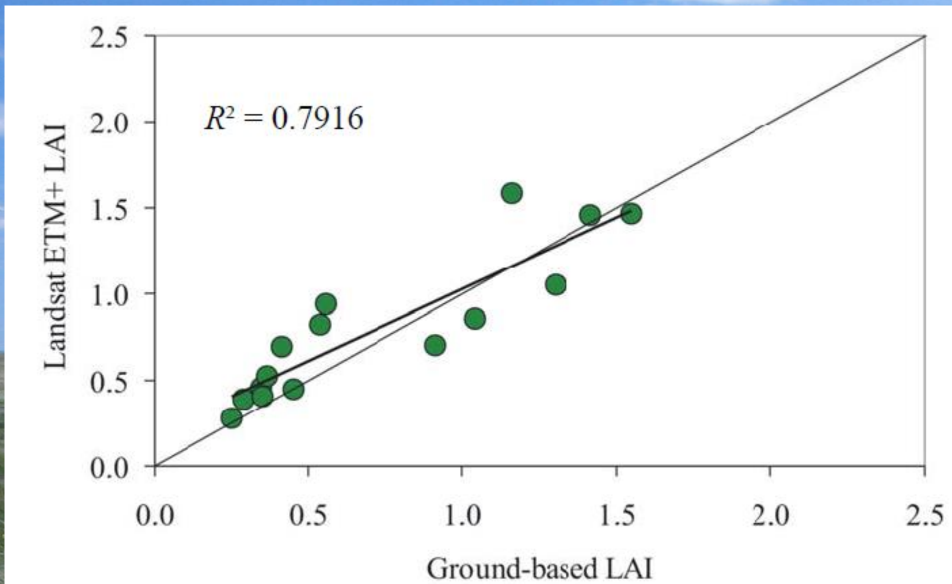
LAI-Data Set for single months from 1982 – 2010

Validation Approach



Land Product Validation group
http://lpvs.gsfc.nasa.gov/

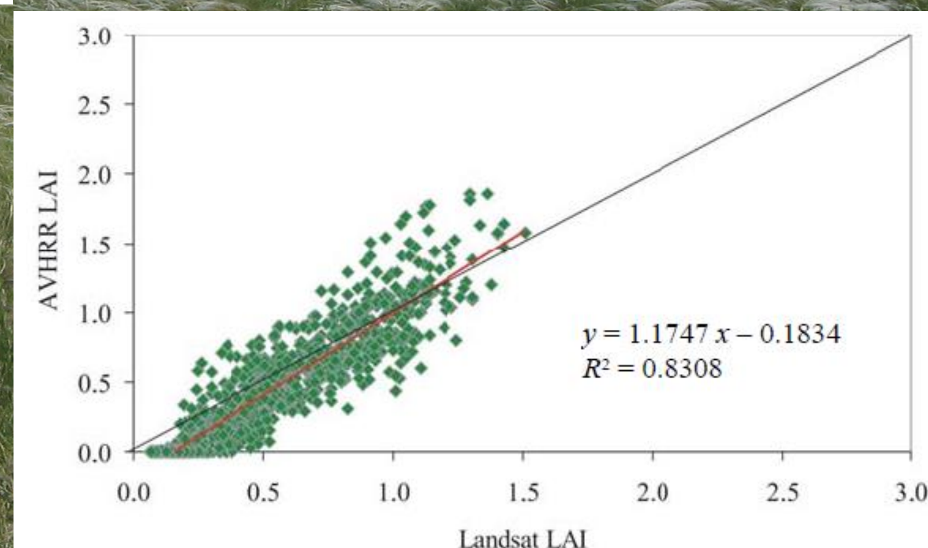
Validation of AVHRR LAI Values for the Grass Land Biome



1. Step: Comparison of Landsat ETM LAI-values with field measurements LAI (2008, Shetsky)
R^2 = 0.79, RMSE=0.08

2. Step: Comparison of Landsat ETM LAI-values with AVHRR LAI-values (Jahr 2008),

pixel by pixel, R^2=0.83,
RMSE= 0.20



Validation of the 8-km Spatial Resolution Kazakhstan-Wide AVHRR LAI Product with other products

The **AVHRR LAI-Göttingen-Data Set** was compared to **LAI_PAL_BU_V3** and **MOD15A2**

Das MODIS LAI-Produkt is available on Earth Observing System Data Gateway:
http://edcimswww.cr.usgs.gov/pub/imswelcome/

Product description:

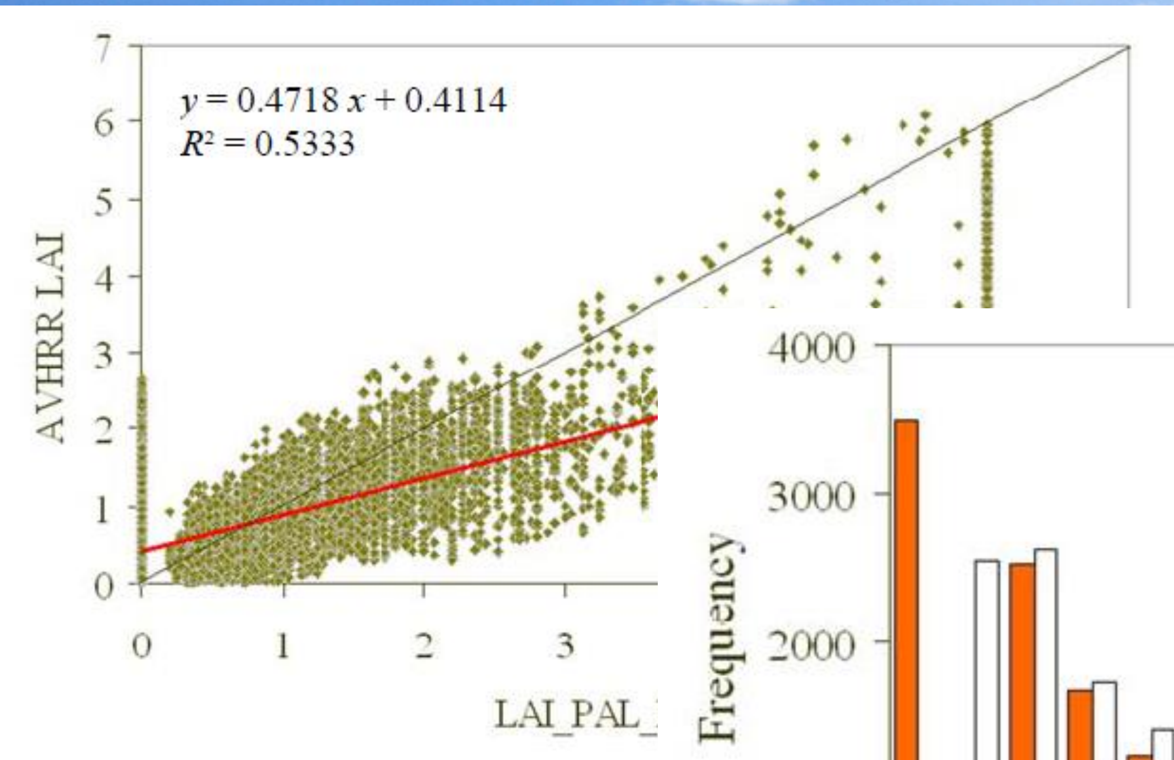
Knyazikhin, Y.; Martonchik, J.V.; Diner, D.J.; Myneni, R.B.; Verstraete, M.; Pinty, B.; Gobron, N. Estimation of vegetation canopy leaf area index and fraction of absorbed photosynthetically active radiation from atmosphere-corrected MISR data. *J. Geophys. Res.* **1998**, *103*, 32239-32256.
Myneni, R.; Hoffman, R.; Knyazikhin, Y.; Privette, J.; Glassy, J.; Tian, H. Global products of vegetation leaf area and fraction absorbed PAR from one year of MODIS data. *Remote Sens. Environ.* **2002**, *83*, 214-231.

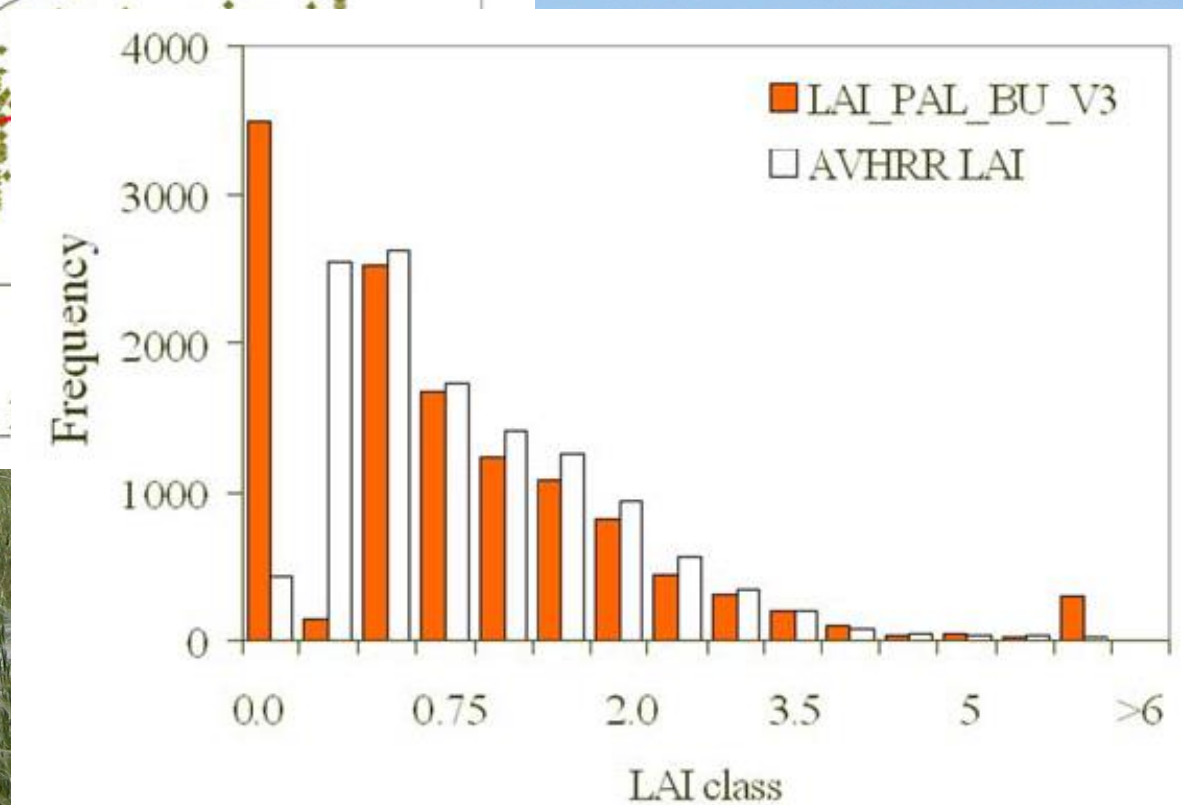
AVHRR LAI Podukt LAI_PAL_BU_V3 is available on:
http://cybele.bu.edu/modismisr/products/avhrr/avhrrlaifpar.html

Product description:

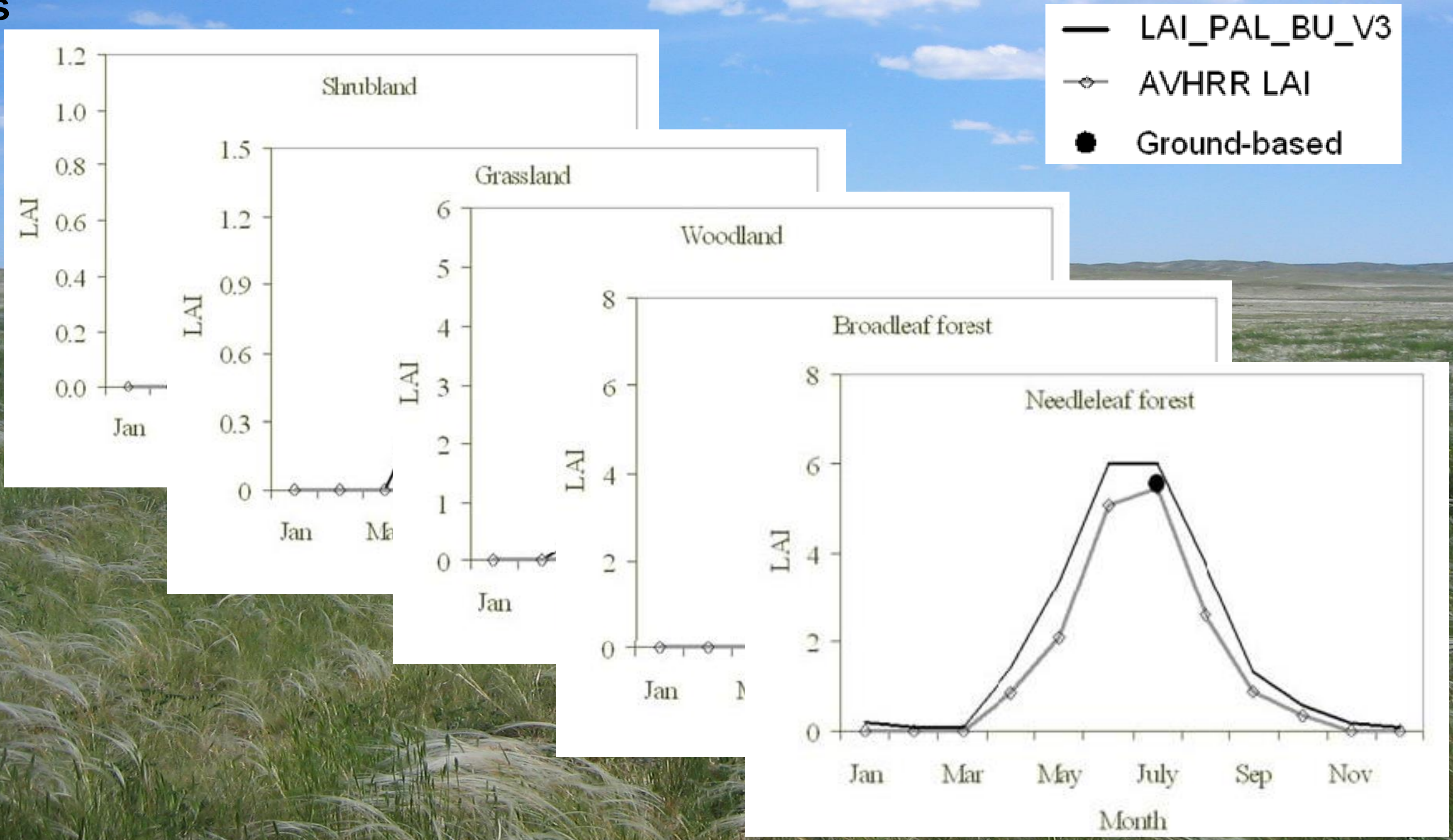
Myneni, R.B.; Nemani, R. R.; Running S.W. Estimation of global leaf area index and absorped par using radiative transfer models. *IEEE Trans. Geosci. Remote Sens.* **1997**, *35*, 1380-1393.

Comparison AVHRRGöttingen-LAI with AVHRR LAI_PAL_BU_V3





Temporal profiles of LAI estimates from the LAI_PAL_BU_V3 product, the Kazakhstan-wide AVHRR LAI product and ground-based measurements at test sites



Summary / Outlook

- Until 2012 validation of global LAI-Time Series for Kazakhstan did not e
- Now, a new national LAI-Data Set of Kazakhstan exist, which is validate
- In all validation tests, the error in LAI (in terms of RMSE) in individual co found to be about 0.15 LAI to 0.4 LAI indicating that the general accurac for remote sensing-based LAI estimates was fulfilled.
- Derivation of LAI-Field-Data and of the national LAI-Data set is documer
- In future a better Standardization for the evaluation of long-time series is

Outlook:

- Integration of LAI-time-series into plant-growth models e.g. BioSTAR http://www.uni-goettingen.de/de/ag-biostar/431252.html
- Cooperation with AgMIP and FACCE-MACSUR
  - Presentation on AGU-AgMIP session (December 11th San Francisco)
  - Presentation on FACCE MACSUR CropM International Symposium and Workshop: Modeling climate change impacts on crop production for food security, Oslo, February 10-12th , Norway, 2014
  - Presentation on Global Land Project conference at Berlin, March 2014, Germany

Propastin, P. and **Erasmi, S.** "A physically based approach to model LAI from MODIS 250m data in a tropical region," *International Journal of Applied Earth Observation and Geoinformation*, vol. 12, no. 1, pp. 47–59, 2010.

Propastin, P. and **Kappas, M.** "Mapping Leaf Area Index in a semi-arid environment of Kazakhstan using fine-resolution satellite data and in situ measurements," *GIScience & Remote Sensing*, vol. 46, no. 2, pp. 212–231, 2009.

Propastin, P. and **Kappas, M.** "Modeling net ecosystem exchange for grassland in Central

Current work: Comparison of LAI3g with LAI Goettingen:

Zaichun Zhu, Jian Bi, Yaozhong Pan, Sangram Ganguly, Alessandro Anav, Liang Xu, Arindam Samanta, Shilong Piao, Ramakrishna R. Nemani and Ranga B. Myneni (2013). Global Data Sets of Vegetation Leaf Area Index (LAI)3g and Fraction of photosynthetically Active Radiation (FPAR)3g Derived from Global Inventory Modeling and Mapping Studies (GIMMS) Normalized Difference Vegetation Index (NDVI3g) for the Period 1981 to 2011. Remote Sens. 2013, 5, 927-948; doi:10.3390/rs502092

Propastin, P. and **Kappas, M.** "Retrieval of coarse-resolution leaf area index over the Republic of Kazakhstan using NOAA AVHRR satellite data and ground measurements," *Remote Sensing*, vol. 4, no. 1, pp. 220–246, 2012.

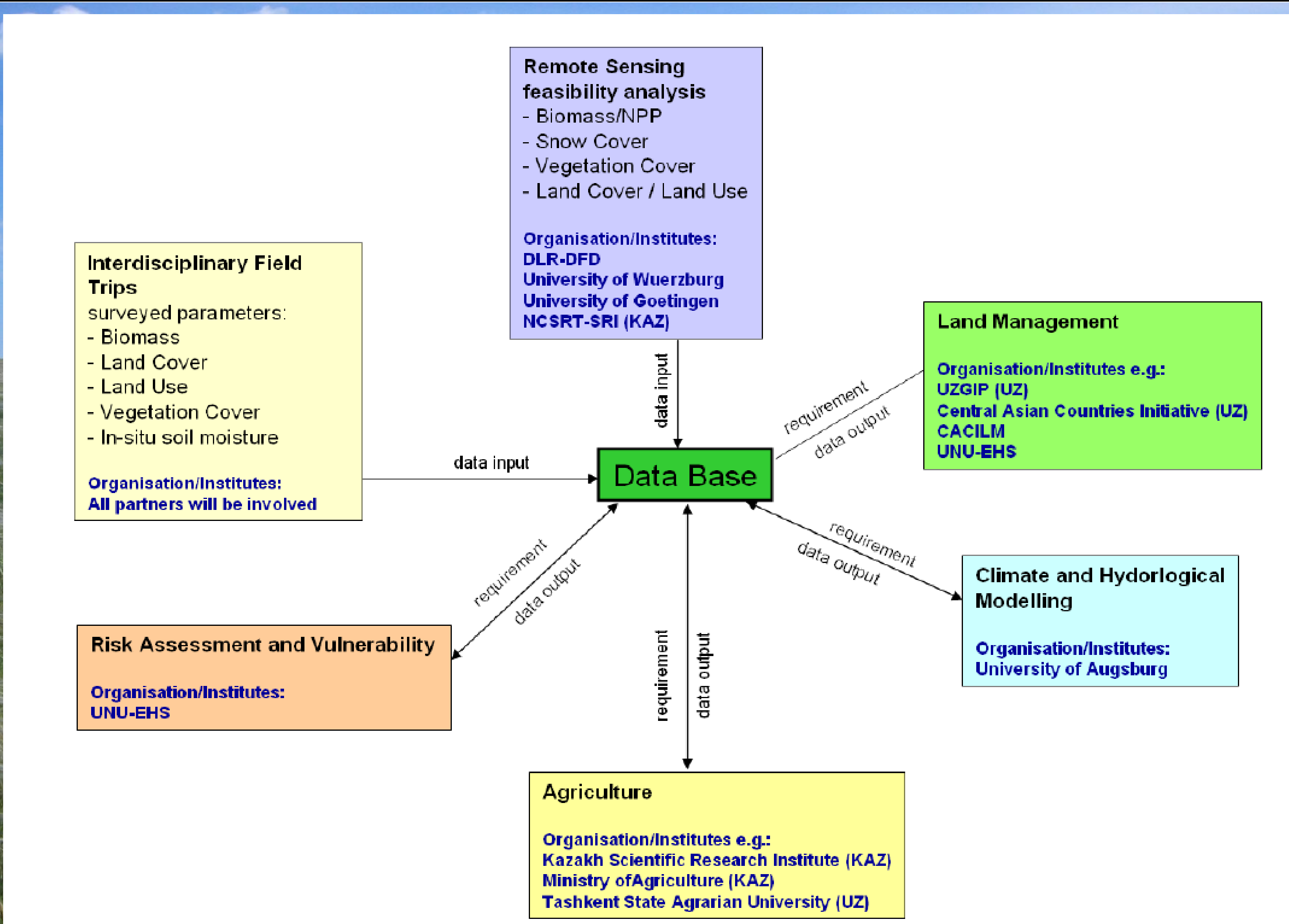
Kappas, M. and **Propastin, P.** Review of Available Products of Leaf Area Index and Their Suitability over the Formerly Soviet Central Asia. Journal of Sensors, Volume 2012. Article ID 582159, doi:10.1155/2012/582159, 2012

Education and Capacity Building in Deriving Biophysical parameters and Biomass with Remote Sensing

Remote Sensing based Technologies and Models for Sustainable Water and Land Management Concepts in Kazakhstan and Uzbekistan (KASUS)

Pilot Project for promoting the Partnership for Sustainable Solutions in Emerging Market and Developing Countries

- **German Aerospace Center (DLR), German Remote Sensing Data Center (DFD) – Land Surface Department (LA), (Principle Investigator in Germany)**
- **National Space Agency Republic of Kazakhstan; National Center of Space Researches and Technologies (NCSRT) – Space Research, Institute (SRI) (Principle Investigator in Kazakhstan**


Remote Sensing feasibility analysis
- Biomass/NPP
- Snow Cover
- Vegetation Cover
- Land Cover / Land Use
Organisation/Institutes:
DLR-DFD
University of Wuerzburg
University of Goetingen
NCSRT-SRI (KAZ)
Interdisciplinary Field Trips
surveyed parameters:
- Biomass
- Land Cover
- Land Use
- Vegetation Cover
- In-situ soil moisture
Organisation/Institutes:
All partners will be involved
data input
data input
Data Base
requirement
data output
Land Management
Organisation/Institutes e.g.:
UZGIP (UZ)
Central Asian Countries Initiative (UZ)
CACILM
UNU-EHS
requirement
data output
requirement
data output
Climate and Hydorlogical Modelling
Organisation/Institutes:
University of Augsburg
Risk Assessment and Vulnerability
Organisation/Institutes:
UNU-EHS
requirement
data output
Agriculture
Organisation/Institutes e.g.:
Kazakh Scientific Research Institute (KAZ)
Ministry ofAgriculture (KAZ)
Tashkent State Agrarian University (UZ)

Partners from Germany:

1. German Aerospace Center (DLR) German Remote Sensing Data Center (DFD) – Land Surface Department (LA) (Principle Investigator in Germany)
2. University of Wuerzburg, Department of Remote Sensing (long-term experience in medium-scale remote sensing of land use and land cover)
3. University of Goettingen, Cartography, GIS and Remote Sensing Section (Long-term experience on landscape ecological and land cover aspects in Kazakhstan)
4. University of Augsburg (long-term experience in modeling regional climate and land use change impact on terrestrial hydrology)
5. United Nations University Bonn: Institute for Environment and Human Security UNU-EHS (long-term experience in land degradation assessment, development of sustainable land management practices to reduce vulnerability, for Central Asia e.g. in the framework of the PALM project)

Partners from Kazakhstan:

1. National Space Agency Republic of Kazakhstan, National Center of Space Researches and Technologies (NCSRT) – Space Research Institute (SRI) (Principle Investigator in Kazakhstan)

3. Institute of Geography of the Republic of Kazakhstan (long term experience in Geomorphology, Cartography, Glaciology and GIS)

4. Kazakh Scientific Research Institute of forage production and pasture within the Kazakh Scientific Research Center for Livestock and Veterinary (experienced in issues related to pasture and pasture management)
5. Ministry of Agriculture of the Republic of Kazakhstan (end user)

Partners from Uzbekistan:

1. Tashkent State Agrarian University (experienced in issues related to pasture and pasture management)
2. Uzbek State Uzgipromeliovodkhoz Institute (UZGIP) (experienced in remote sensing of land and water issues)
3. Central Asian Countries Initiative for Land Management (experienced in remote sensing of land and water issues)