Регрессионные модели оценки урожайности сельскохозяйственных

культур по спутниковым и агрометеорологическим данным

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 Киев, Украина

Context – CRDF project

- **Title**:
  - Analysis of Climate Change & Food Security based on Remote Sensing & In Situ Data Sets

- **Project duration**:
  - 2 years (2011-2012)

- US Principal Investigator
  - **Felix Kogan**, PhD, National Oceanic and Atmospheric Agency (NOAA)

- **Overall goal of the project**
 - to analyze climate change and food security based on remote sensing and in situ data sets.
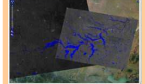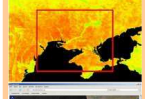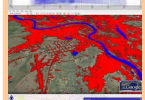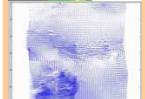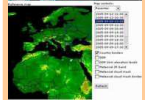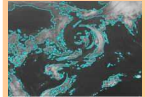
Results
# **Winter wheat yield forecasting using satellite data**

Winter wheat yield forecasting

- Empirical regression model based on NDVI data derived from MODIS and statistical data on winter wheat
  - Time period: 2000-2009
- NDVI averaged for oblasts by crop masks
- Trend eliminated from yield
- Regression model
  - Robust regression
- Regression model is specific for each oblast
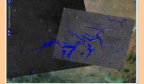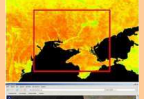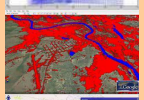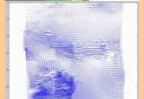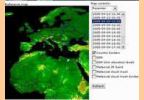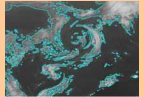
Модели для областей Украины. Выбор признаков

Днепропетровская обл.

Черниговская обл.

Корреляция среднего NDVI и урожайности на протяжении года (Днепропетровская и Черниговская области)

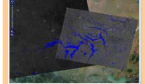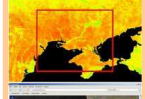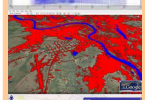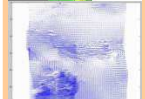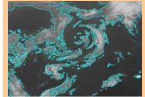Уменьшение ошибки при использовании среднего ndvi в качестве предиктора

Winter wheat yield forecasting

- ## Cross-validation
  - leave-one-out cross-validation (**LOOCV**)
  - using a single observation from the original sample as the testing data, and the remaining observations as the training data
- ## Criteria
  - RMSE on testing data

Feature selection

Dependence of RMSE on test data on NDVI DOY (min RMSE=1.81, DOY=129)

Crimea

Dependence of RMSE on test data on NDVI DOY (min RMSE=5.41, DOY=97)

Vinnytsa
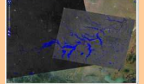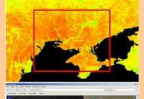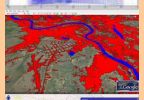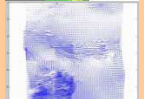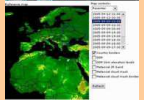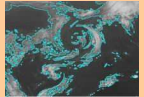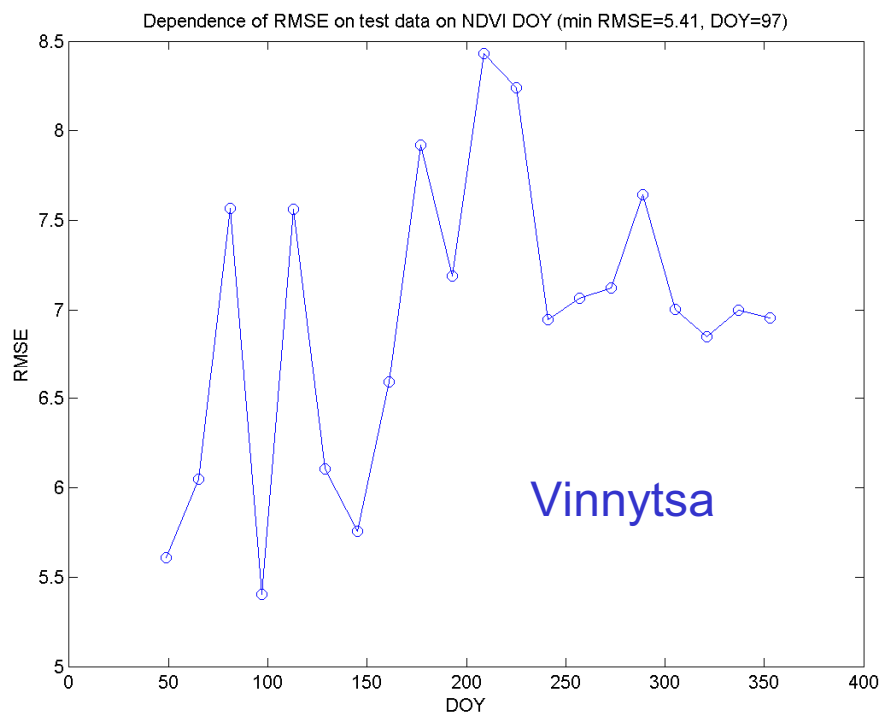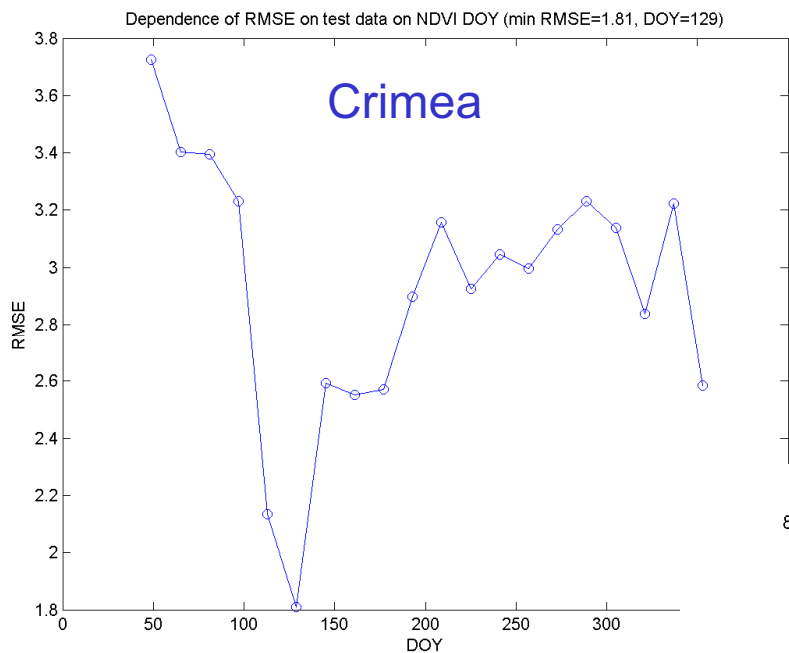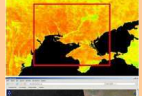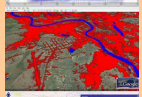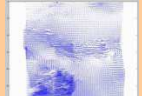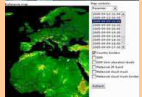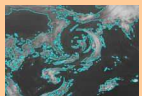
Oblast	DOY	RMSE	Eff
Volyn Oblast	209	3.274	1.018
Zhytomyr Oblast	97	2.898	1.598
Zakarpattia Oblast	321	2.694	1.716
Ivano-Frankivsk Oblast	193	2.771	1.22
Lviv Oblast	113	2.486	0.993
Rivne Oblast	97	3.411	1.214
Chernihiv Oblast	97	3.366	1.267
Vinnytsia Oblast	97	5.405	1.114
Kiev Oblast	97	4.083	1.616
Poltava Oblast	129	4.286	2.09
Sumy Oblast	145	3.758	1.766
Ternopil Oblast	97	3.914	1.214
Kharkiv Oblast	129	3.846	2.443
Khmelnytskyi Oblast	49	3.868	1.421
Cherkasy Oblast	129	6.473	1.35
Chernihiv Oblast	97	3.366	1.267
Dnipropetrovsk Oblast	145	5.302	2.048
Donetsk Oblast	129	4.41	1.871
Zaporizhia Oblast	129	3.797	1.947
Kirovohrad Oblast	129	4.506	2.324
Luhansk Oblast	129	4.189	1.829
Mykolaiv Oblast	129	4.086	2.116
Odessa Oblast	129	5.321	1.589
Kherson Oblast	129	3.927	1.796
Crimea	129	1.809	1.424

Plane Polissya Zone
Forest-Steppe Zone
Steppe Zone
Mountain Zone

	Zone	Av. eff.
	Plane Polissya	1.289
	Forest-Steppe	1.587
	Steppe	1.883

Distribution of DOY

- Distribution of DOYs over oblasts that minimize RMSE on test data
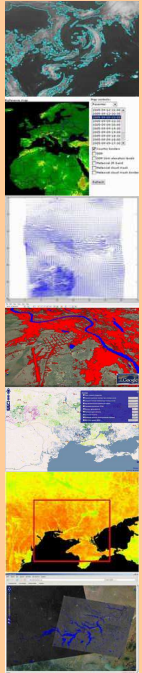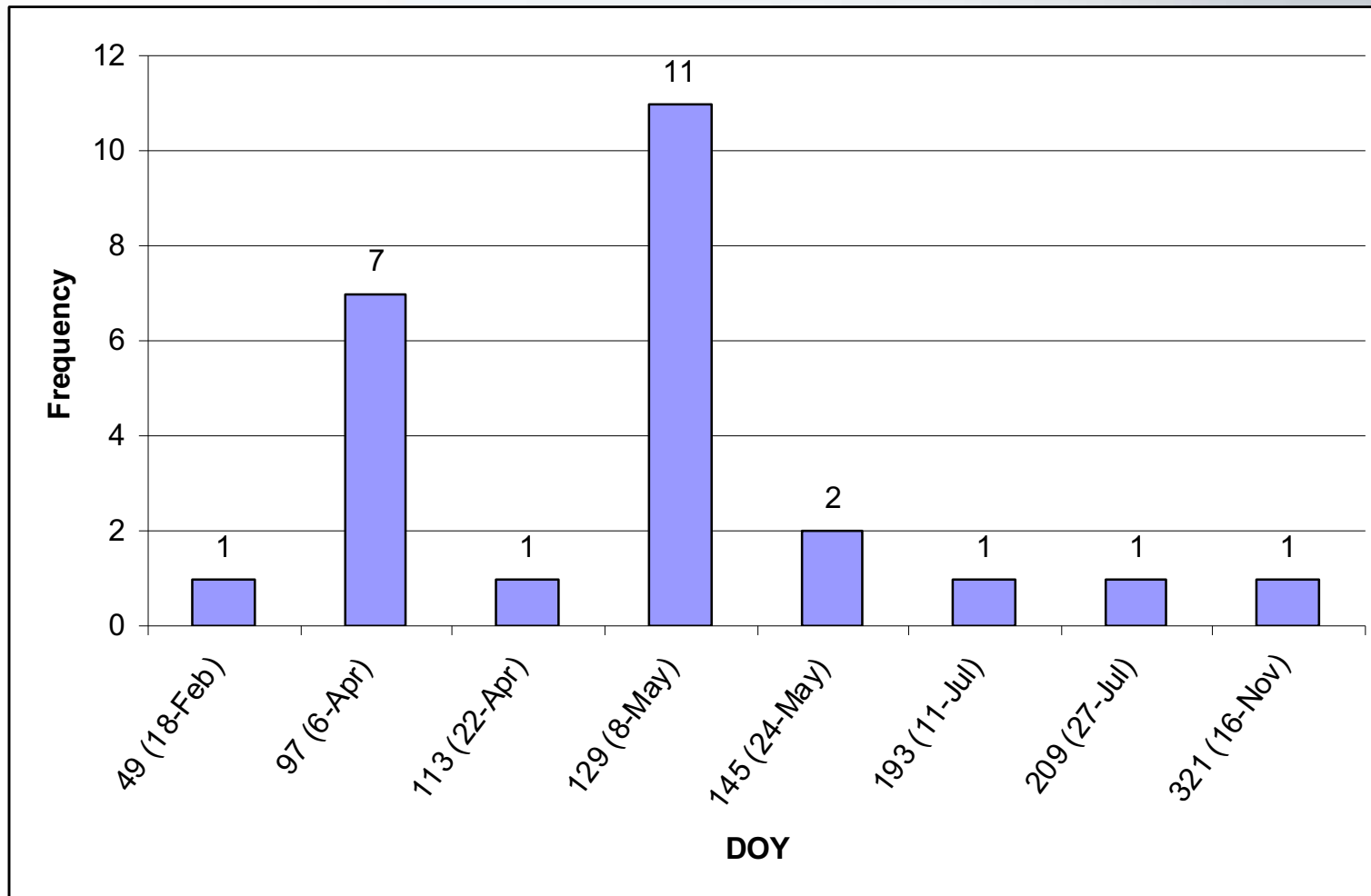
Observed vs predicted yield on test data (for all oblasts)

R2 = 0.75

Predicted yield (centner/ha)

Observed yield (centner/ha)
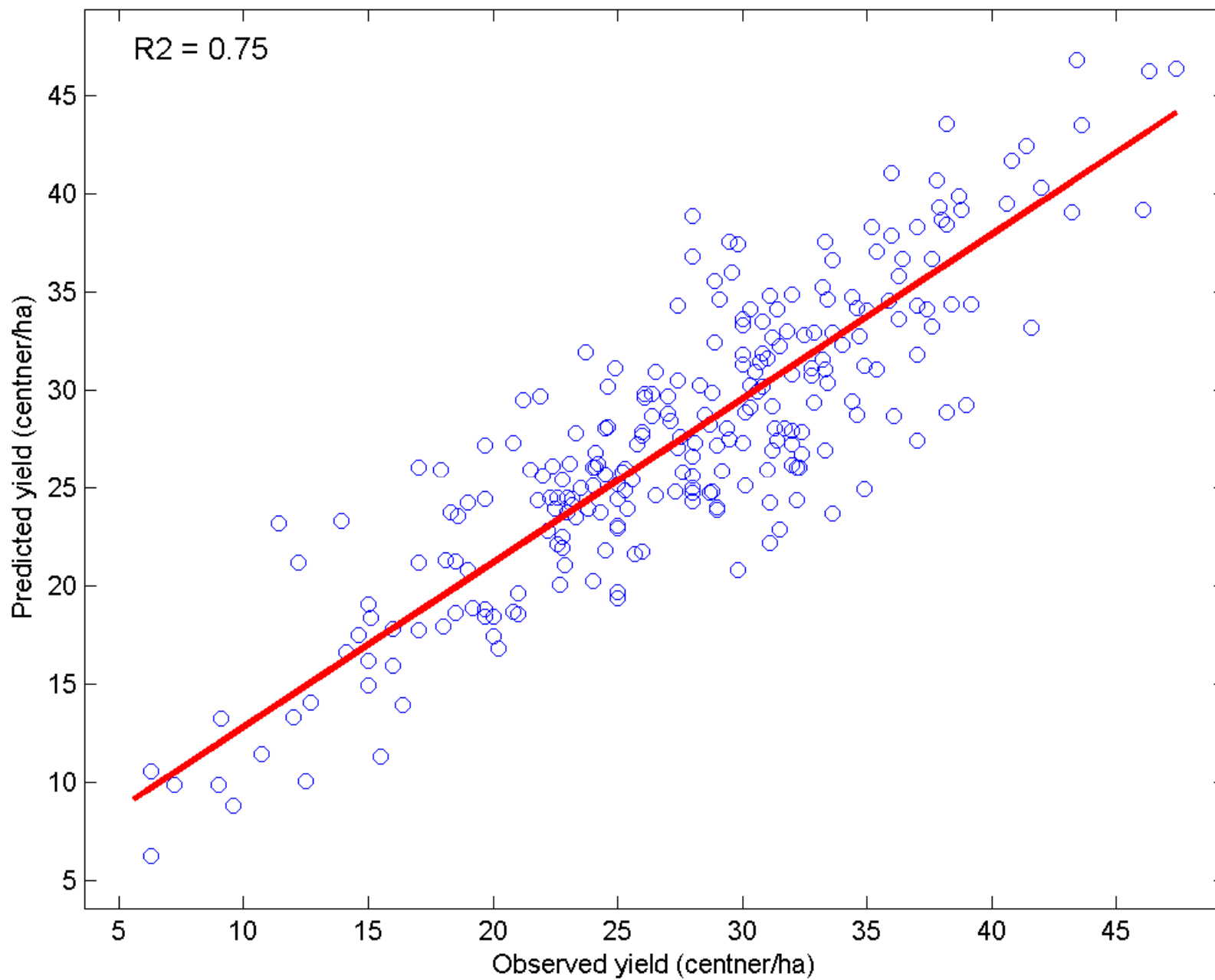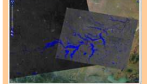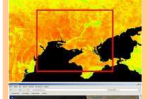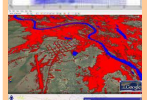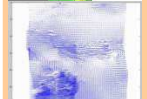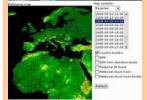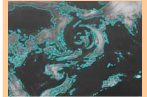
Results
Winter wheat yield estimation using agrometeorological data

Objective

- To model the relationship between crop productivity (in particular winter wheat) and main climatic parameters
  - Maximum temperature
  - Minimum temperature
  - Average temperature
  - Precipitation
  - Soil moisture
    - 0-20 cm depth
    - Available for months: Sept, Oct, Apr, May, June
- Methodology
  - Correlation analysis
  - Linear multivariate regression
  - Non-linear multivariate regression
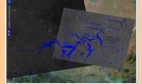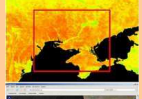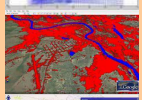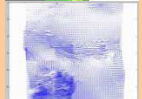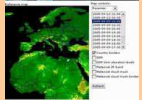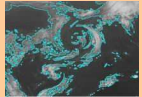
Correlation between maximum temperature and yield

№	Crim	Dnepr	Don	Zap	Kirov	Lug	Mykol	Odessa	Kherson
7	0.028394	-0.48934	-0.19916	-0.35864	-0.24458	-0.031357	-0.33754	0.14953	-0.45106
8	0.68393	0.15036	-0.21285	-0.01219	0.22505	-0.18567	0.52422	0.47785	0.16628
9	0.12035	-0.31091	0.19388	0.0040819	-0.58689	0.0042976	-0.33512	-0.52793	0.025162
10	0.15613	0.0050704	-0.20699	-0.047397	-0.091975	-0.31676	0.041256	0.070695	0.14046
11	-0.2756	0.3727	0.047867	-0.12432	-0.33289	0.18936	0.019755	-0.11093	0.045587
12	0.097253	0.29823	0.099358	0.13126	0.17035	-0.19041	0.28216	0.16529	0.20881
1	-0.16606	0.63236	0.51598	0.24708	0.25303	0.391	0.35301	0.26233	0.38443
2	0.53168	0.39994	0.54325	0.3951	0.6185	0.40004	0.6659	0.73938	0.51766
3	**0.66576**	**0.62146**	**0.65599**	**0.78493**	**0.51085**	**0.41348**	**0.5907**	**0.85968**	**0.73434**
4	0.59713	-0.016151	-0.13286	0.17282	-0.70793	-0.042479	-0.24879	-0.11057	0.47367
5	-0.31848	-0.64692	-0.50068	-0.62155	-0.70971	-0.31977	-0.84414	-0.63519	-0.71678
6	-0.16975	-0.52878	-0.41524	-0.38899	-0.45837	-0.4801	-0.32603	-0.10596	-0.47221

Correlation between minimum temperature and yield

№	Crim	Dnepr	Don	Zap	Kirov	Lug	Mykol	Odessa	Kherson
7	-0.41662	0.2813	0.15103	0.012797	0.21299	0.5339	0.3039	0.24178	-0.042668
8	0.29938	-0.26698	0.22591	0.062019	-0.4164	0.065315	-0.029812	-0.39759	0.0028998
9	-0.23182	0.060864	-0.14665	-0.23218	0.31486	0.070909	-0.13485	-0.35152	-0.020444
10	0.15472	-0.26534	-0.026552	-0.33768	-0.11899	0.11331	-0.13834	-0.26121	-0.25858
11	-0.32862	0.12824	0.084218	-0.1159	0.12995	0.016175	0.21904	0.17784	0.011755
12	0.71624	0.16197	0.1543	0.19255	0.32885	0.0451	0.43278	0.25153	0.36252
1	-0.17515	0.56079	0.2928	0.13224	0.38556	0.55532	0.20403	0.13767	0.096442
2	0.083637	0.27467	0.26774	0.10612	0.54175	0.30203	0.54004	0.36172	0.36274
3	0.14942	0.30964	0.50986	0.16943	-0.015934	0.3601	0.047862	0.19136	-0.16842
4	0.35385	-0.13256	-0.24131	-0.019246	-0.23256	-0.27213	-0.17588	-0.096503	-0.0088771
5	-0.35995	0.12722	0.15198	0.036682	-0.039337	0.36516	-0.068365	0.069377	-0.47783
6	-0.20339	-0.066609	0.14397	0.16411	-0.45289	0.055353	-0.30575	-0.74256	-0.1294

Correlation between average temperature and yield

№	Crim	Dnepr	Don	Zap	Kirov	Lug	Mykol	Odessa	Kherson
7	-0.29942	-0.35126	-0.24725	-0.29955	-0.35319	-0.14199	-0.34068	-0.29236	-0.35027
8	0.34911	0.1372	0.11163	0.13711	0.25645	0.13735	0.35313	0.53017	0.21105
9	-0.20768	-0.54585	-0.5522	-0.45706	-0.58285	-0.31288	-0.6098	-0.5268	-0.47981
10	-0.11309	0.033319	-0.11353	-0.059982	0.24779	-0.28074	0.11742	-0.018076	-0.0026652
11	-0.56186	0.026467	-0.085765	-0.10321	0.029687	-0.07696	0.050242	-0.15798	-0.25548
12	0.73051	0.32459	0.25071	0.38424	0.32825	0.015717	0.30901	0.30539	0.4968
1	-0.25626	0.17545	0.2493	0.06493	0.14072	0.30679	-0.017265	-0.019324	-0.046139
2	0.41033	0.48671	0.49646	0.41528	0.55871	0.3154	0.6022	0.63751	0.53412
3	0.69726	0.51643	0.58657	0.54978	0.47441	0.35182	0.5327	0.69129	0.64766
4	0.81435	0.37751	0.31695	0.4645	0.36667	0.2552	0.37446	0.49336	0.60399
5	**-0.79492**	**-0.68007**	**-0.44278**	**-0.71048**	**-0.78131**	**-0.14451**	**-0.87952**	**-0.87296**	**-0.84323**
6	-0.2975	-0.24814	-0.17757	-0.33558	-0.42477	-0.34793	-0.44075	-0.5314	-0.39467

Correlation between precipitation and yield

№	Crim	Dnepr	Don	Zap	Kirov	Lug	Mykol	Odessa	Kherson
7	-0.44383	-0.05185	-0.17968	-0.076432	0.32844	-0.062767	0.35819	0.094325	0.29632
8	-0.33229	-0.071638	0.28205	0.12939	-0.26735	-0.035257	-0.31541	-0.50435	-0.078802
9	-0.59345	-0.001362	-0.037385	-0.32289	0.12356	0.40803	0.35673	0.33836	-0.09701
10	-0.44322	-0.3653	-0.7031	-0.53118	-0.27822	-0.5492	-0.1809	-0.17297	-0.36161
11	0.12658	-0.2417	-0.32216	-0.3028	0.19192	-0.27842	-0.093623	0.17322	-0.16728
12	0.45188	0.1798	-0.22143	0.21909	-0.0036298	-0.19411	0.10072	0.19536	0.22254
1	-0.28507	-0.48694	-0.091946	-0.066088	-0.37517	-0.24441	-0.2021	-0.26254	-0.22865
2	-0.20136	0.28383	0.052988	0.13561	0.033568	-0.020791	-0.071412	-0.45491	-0.22081
3	0.32626	0.15665	-0.16078	-0.090452	0.20544	-0.057225	0.40517	0.4879	0.20706
4	0.28161	0.40718	0.44374	0.34788	0.19804	0.53928	0.0048345	0.034649	0.49343
5	**0.4525**	**0.42638**	**0.41399**	**0.48975**	**0.75568**	**0.45475**	**0.69528**	**0.50943**	**0.52469**
6	0.5692	-0.073222	-0.08988	0.31157	0.38893	-0.18582	0.70188	0.40401	0.34927

Correlation between soil moisture and yield

№	Crim	Dnepr	Don	Zap	Kirov	Lug	Mykol	Odessa	Kherson
4	-0.40062	-0.14184	0.19829	0.033671	-0.034916	0.48005	0.11103	-0.012341	0.0035585
5	-0.5799	-0.2638	-0.4639	-0.06519	-0.67087	-0.45136	0.3498	-0.26371	0.23095
6	0.35654	0.27268	0.36986	0.52899	-0.093773	0.18641	0.22475	0.0076216	0.39847
9	**0.52945**	**0.3526**	**0.26894**	**0.31585**	**0.49607**	**0.44526**	**0.7434**	**0.41794**	**0.61782**
10	0.74869	0.28547	-0.052434	0.22831	0.24574	-0.13895	0.68106	0.27564	0.41003

Regions normalization

- Split by agroclimatic zones
- Detrend
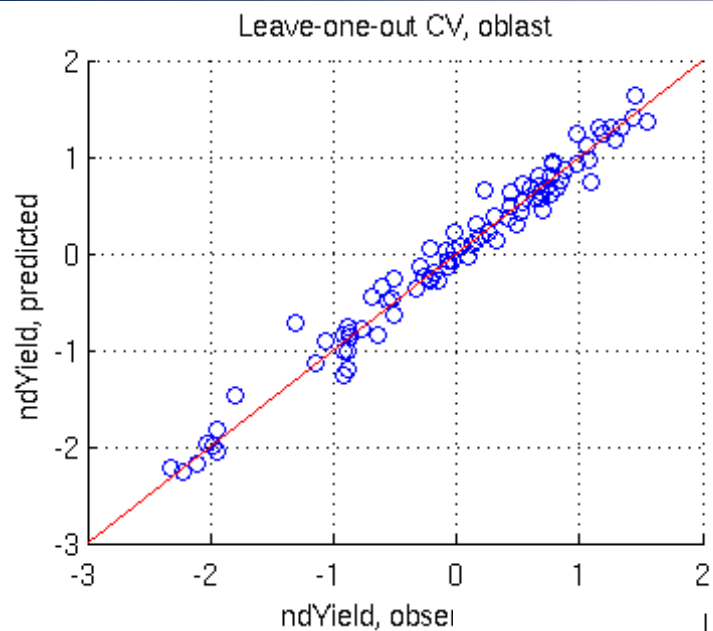- Normalize by std
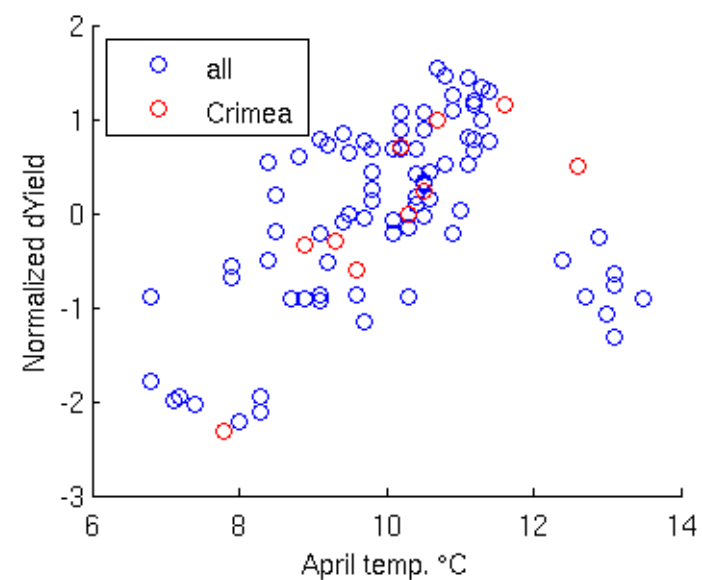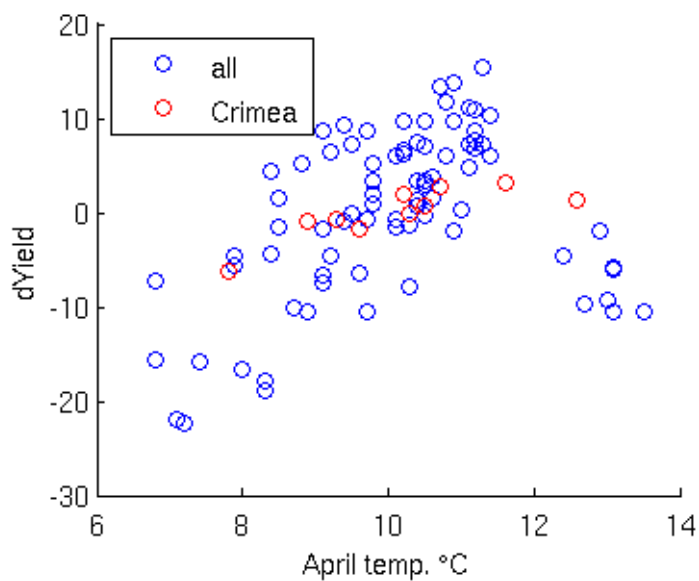
Non-linear effects
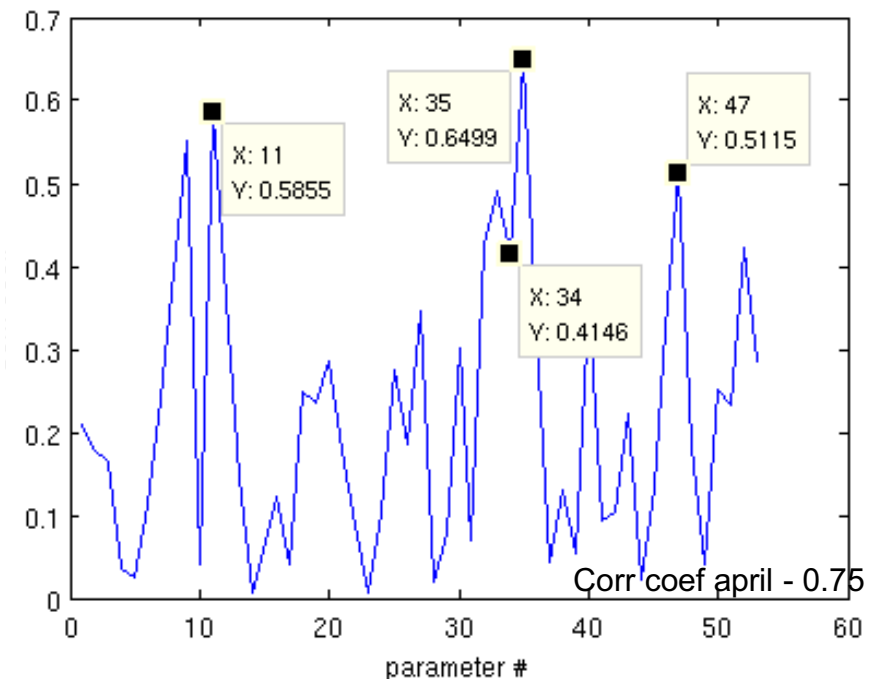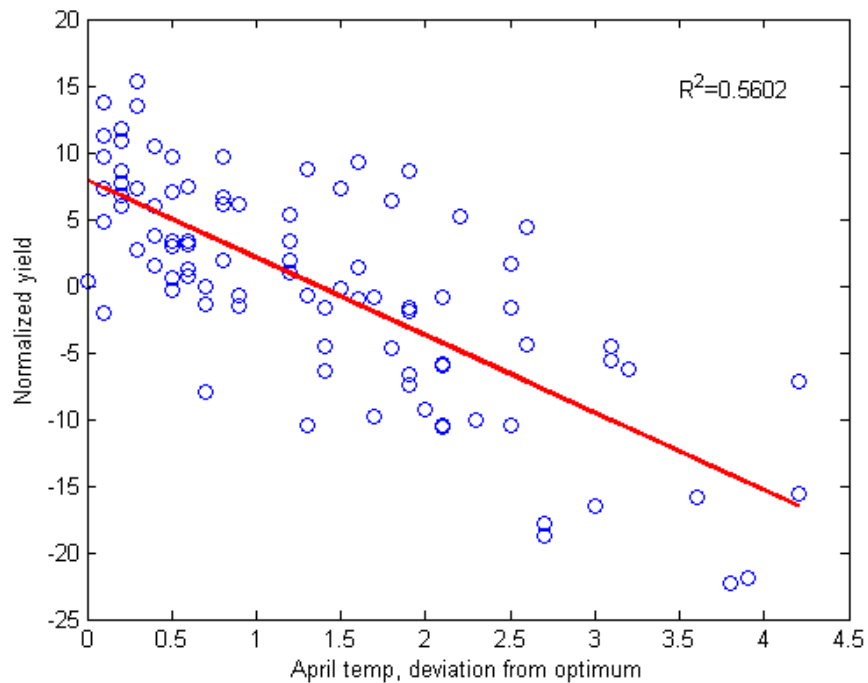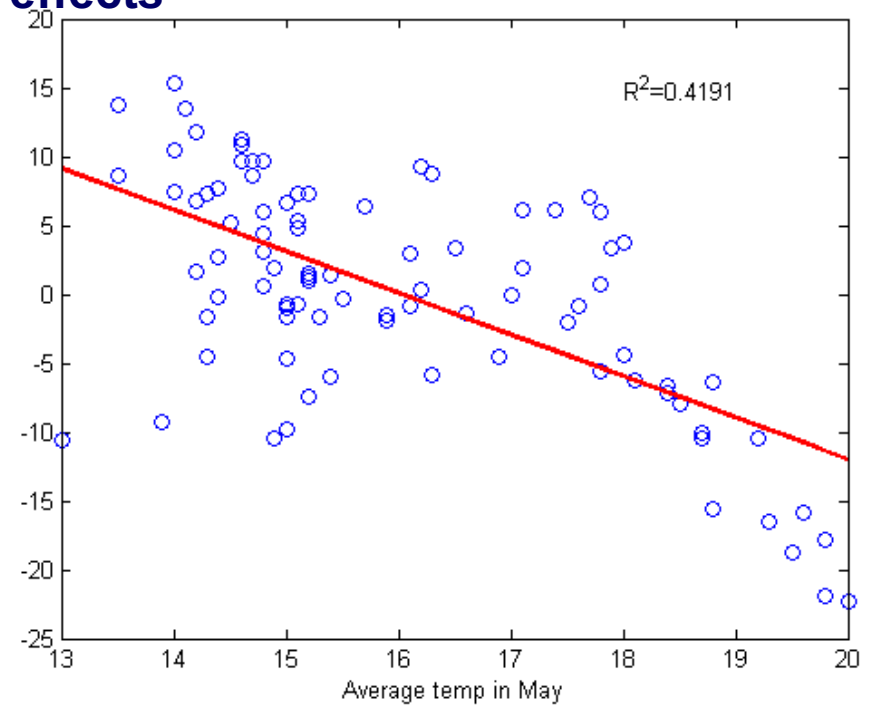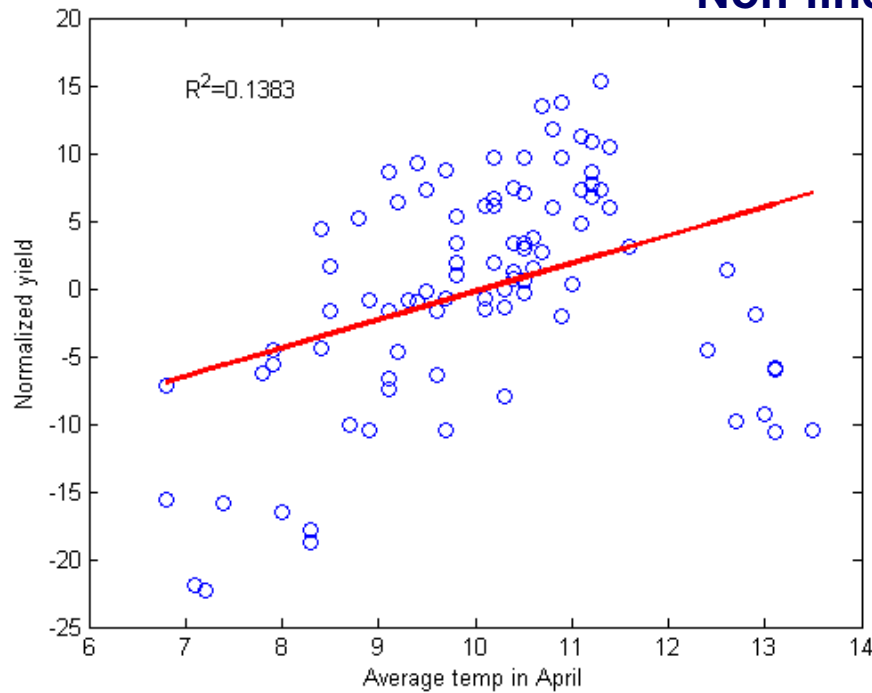
Nonlinear regression

- Neural Networks
- Kernel methods
  - Support Vector Machines
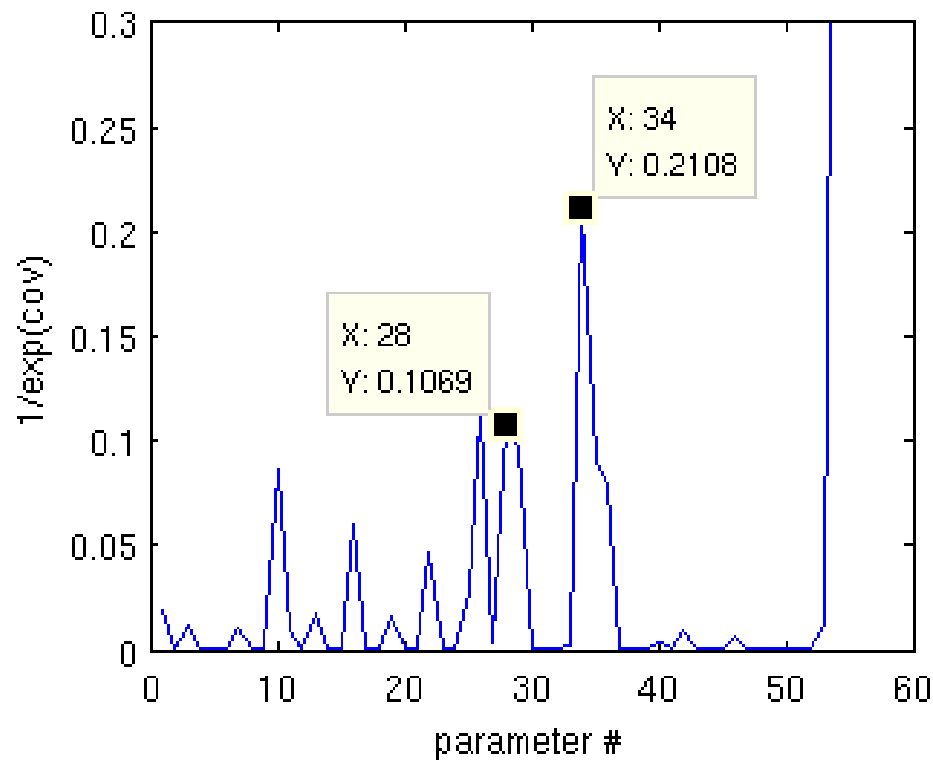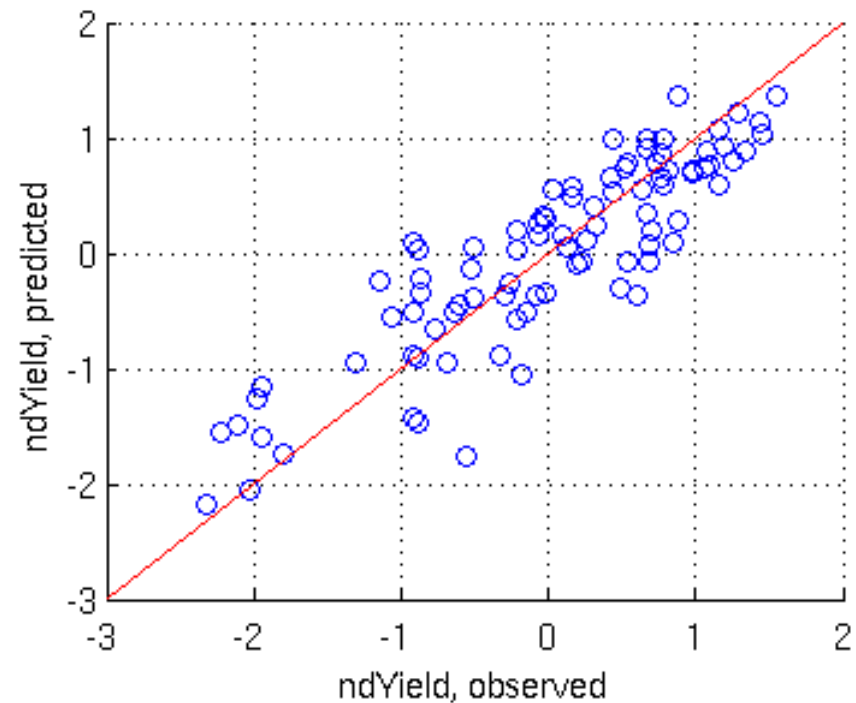 - Gaussian processes regression
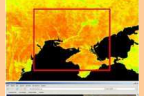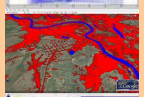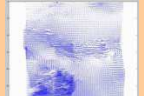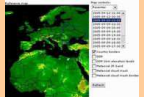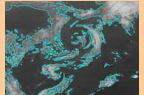
Gaussian processes regression
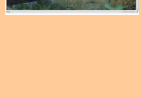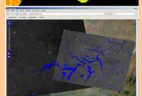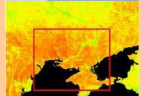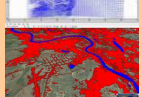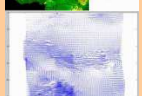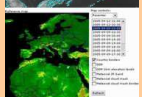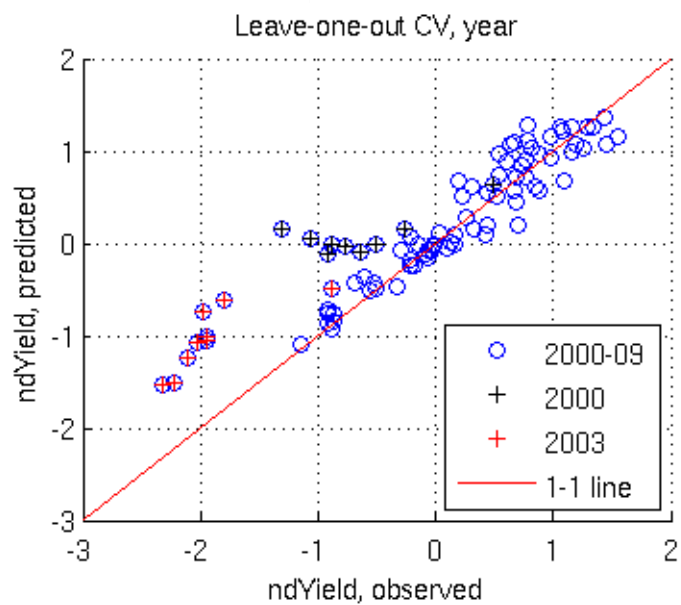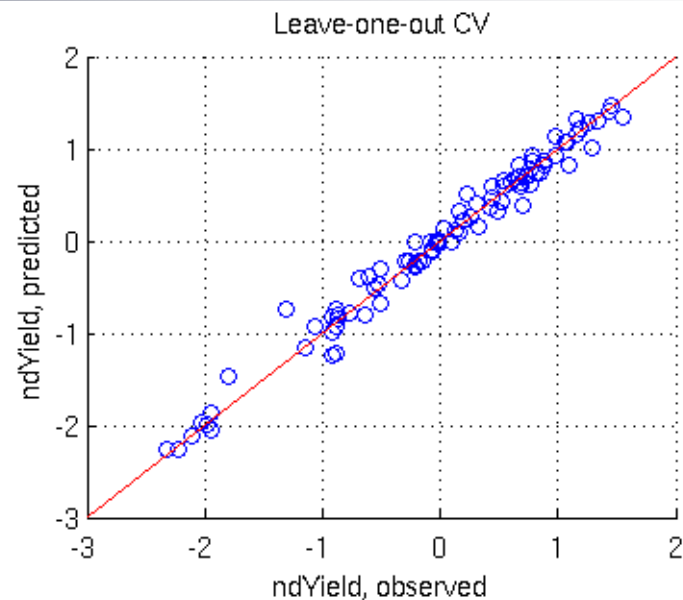
Feature selection

- Most relevant predictors
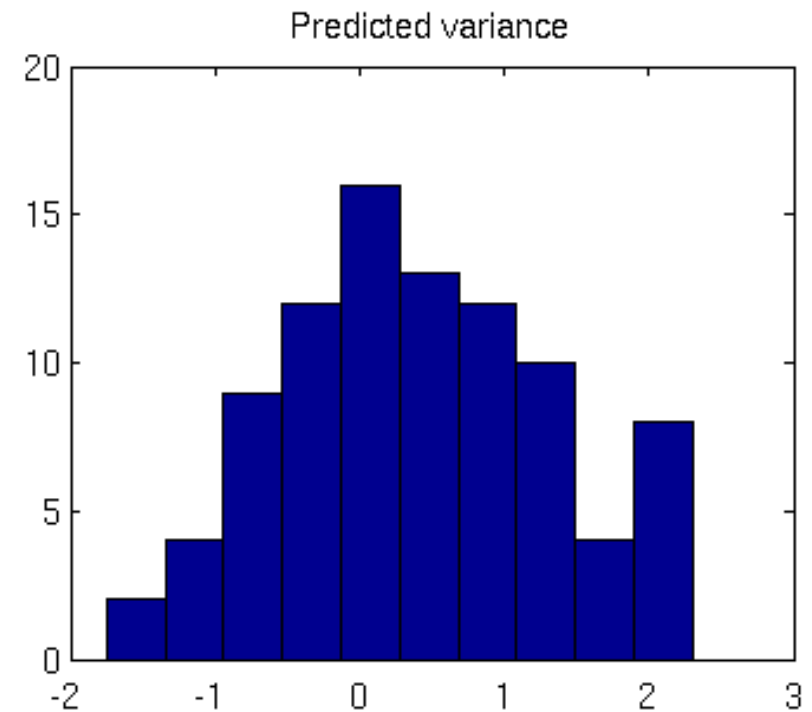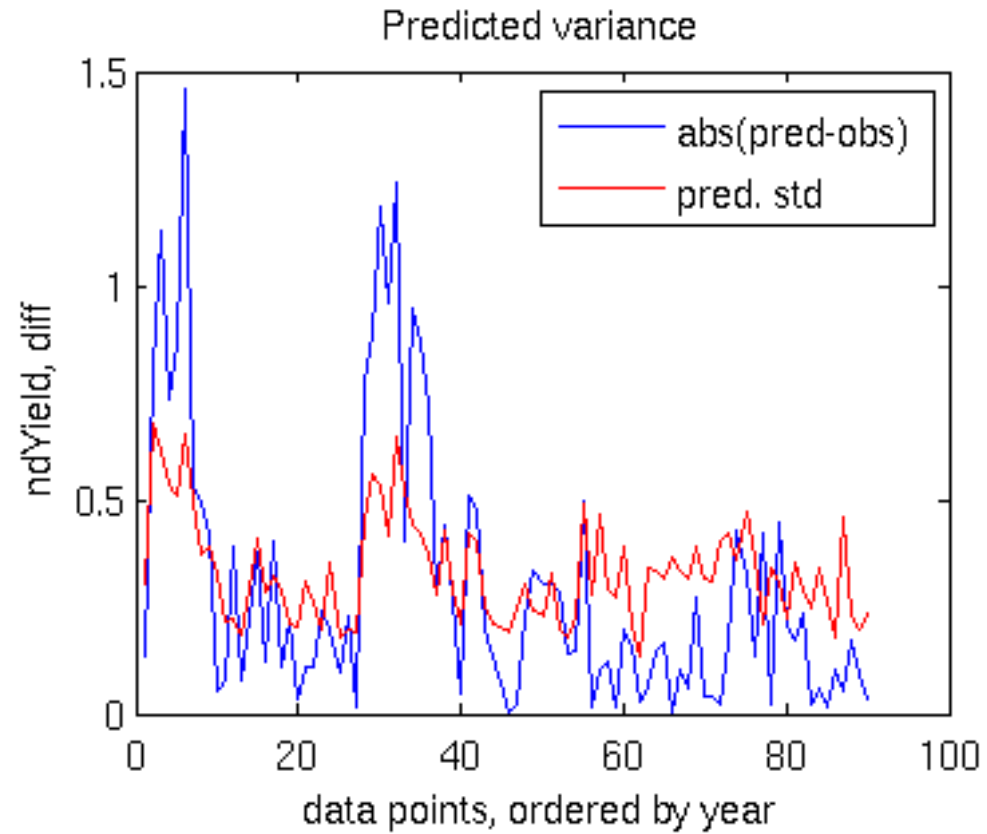 - Av temp (August, October, April)

Parameter relevance

X: 34
Y: 0.2108

X: 28
Y: 0.1069

1/exp(cov)

parameter #

Leave-one-out CV. Set1

ndYield, predicted

ndYield, observed

Variance prediction

Efficiency

Oblast	Eff.
Dnipropetrovsk Oblast	2.999
Donetsk Oblast	2.322
Zaporizhia Oblast	1.800
Kirovohrad Oblast	2.469
Luhansk Oblast	1.845
Mykolaiv Oblast	1.855
Odessa Oblast	2.511
Kherson Oblast	2.759
Crimea	3.592

Thank you!