Development and Validation of Remote Sensing Products of Hydrological Cycle in Northwest China

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Project ID: 10649
Posters

- Predicting River Summer Runoff in the Heihe River Watershed in China on the Basis of MODIS Snow Cover Data (No. 44)
- Satellite Snow Product for River Runoff Prediction: Towards an Operational Tool (No. 29)
- Estimation of High-resolution Soil Moisture and its Freeze/Thaw Status by Using ENVISAT/ASAR Global Mode Backscattering (No. 34)
- Improving Estimation of Evapotranspiration under Water-Limited Conditions Based on SEBS and MODIS Data in Arid Regions (No. 35)
- A Revised Temporal Scaling Method to Yield Improved Regional ET Estimates (No. 36)
- Multivariate Land Data Assimilation at Global Scale (No. 37)
Outline

- Objective & background
- Progress on the development and validation of RSPs of water cycle
- Sino-Europe collaboration
- Summary and perspective
1. Objective & background

- The overall objective of this project is to close the water cycle at river basin scale.

- Water budget components: precipitation, evapotranspiration (ET), soil moisture (SM), snow water equivalent (SWE), runoff, and groundwater storage.

- These products, in combination with hydrology and land surface modeling will be integrated by data assimilation methods to close the land water budget at basin scale.
Difference between global and basin-scale RSPs

**Global RSP**
- Global land cover classification
- Less consideration of terrain and geomorphic effects
- Less a priori knowledge, less accuracy
- Single-sensor data product, medium to coarse spatial and temporal resolution

**Basin-scale RSP**
- Detailed regional-scale land cover classification
- Localized algorithm
- Terrain and geomorphic effects to be considered.
- Big amount of *in situ* data, rich a priori knowledge, controllable accuracy
- Based on multi source and multi-scale data, improved spatial and temporal resolution
Study area

China: Heihe River Basin (HRB)
2. Progress on the development and validation of remote sensing products (RSPs) of water cycle

- Precipitation
- Snow
- Soil moisture
- Evapotranspiration
- Groundwater
- Data assimilation
2.1 Precipitation

- Based on the evaluation results of four precipitation products over the HRB (reported in 2014 symposium)

- To integrate various precipitation observations via data assimilation

Pan XD et al., JHM, 2014;
Pan XD et al., Remote Sens., 2015
Two nested domains

Assimilation scheme

- Rain Gauge
- Doppler radar assimilation
- WRF control
- TRMM WRF4DVar
- FY WRF4DVar
Different increments of 24h results between simulation and data assimilation for air temperature and water vapor content.

2008.06.22:00

2008.06.23:00
2.2 Snow

- Fractional snow cover area products were produced at river basin scale based on improved approach (reported in 2014 symposium)
2.2 Snow

- Predicting river summer runoff in the Heihe river watershed in China on the basis of MODIS snow cover data
- Estimation of snow water equivalent with C-band SAR: Experiment and analysis
- Improving mountainous snow cover fraction mapping via artificial neural networks combined with MODIS and ancillary topographic data
2.2.1 Predicting river summer runoff in the Heihe river watershed in China on the basis of MODIS snow cover data

This study looks into the relationship between the total runoff volume in summer and the snow covered area during winter months.

MODIS Daily Snow Cover

Characteristics

- 500m resolution
- Pixel values in between 0 and 255
- Classification: land (no snow), snow, lake, cloud, no decision
Prediction model - Qilian

\[ V_{Mar.12-Oct.21} = 0.20 + 0.0017 \times P_{M, Oct.16-Mar.1} \]

POSTER No. 44
2.2.2 Estimation of snow water equivalent with C-band SAR: Experiment and Analysis

Sun SB et al., AAA, 2015
Snow water storage distribution based on SAR SWE mapping. (a) Aspect, and (b) elevation.

Estimation result of SWE

Sun SB et al., AAA, 2015
2.2.3 Improving mountainous snow cover fraction mapping via artificial neural networks combined with MODIS and ancillary topographic data

Hou JL et al., TGRS, 2014
<table>
<thead>
<tr>
<th>Input/ Hidden Number</th>
<th>Test1</th>
<th>Test2</th>
<th>Test3</th>
<th>Test4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RMSE</td>
<td>R</td>
<td>RMSE</td>
<td>R</td>
</tr>
<tr>
<td>MOD10</td>
<td>-/-</td>
<td>0.094</td>
<td>0.902</td>
<td>0.086</td>
</tr>
<tr>
<td>Exp.1</td>
<td>7/15</td>
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<td>0.964</td>
<td>0.049</td>
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<tr>
<td>Exp.2</td>
<td>8/17</td>
<td>0.047</td>
<td>0.970</td>
<td>0.044</td>
</tr>
<tr>
<td>Exp.3</td>
<td>8/17</td>
<td>0.049</td>
<td>0.967</td>
<td>0.046</td>
</tr>
<tr>
<td>Exp.4</td>
<td>8/17</td>
<td>0.051</td>
<td>0.965</td>
<td>0.048</td>
</tr>
<tr>
<td>Exp.5</td>
<td>9/19</td>
<td>0.045</td>
<td>0.973</td>
<td>0.043</td>
</tr>
<tr>
<td>Exp.6</td>
<td>10/21</td>
<td>0.045</td>
<td>0.973</td>
<td>0.042</td>
</tr>
<tr>
<td>Exp.7</td>
<td>10/21</td>
<td>0.041</td>
<td>0.977</td>
<td>0.040</td>
</tr>
<tr>
<td>Exp.8</td>
<td>11/23</td>
<td>0.041</td>
<td>0.977</td>
<td>0.039</td>
</tr>
</tbody>
</table>

**SCF: reflectance of 7 bands + DEM + NDSI + LST + MOD10**

Hou JL et al., TGRS, 2014
2.3 Soil moisture

- Upscaling of SM measurements from WSN over HRB; Downscaling of ASCAT SWI (reported in 2014 symposium)
- Estimation of High-resolution SM by Using ENVISAT/ASAR GM Backscattering Data in the Upper Reaches of the HRB
- Active and passive L-band microwave RS for soil moisture: a test bed for SMAP fusion algorithms in Rur catchment
2.3.1 Estimation of High-resolution SM by Using ENVISAT/ASAR GM Mode Backscattering Data in the Upper Reaches of the HRB

OBJECTIVES:
• Mapping 1km resolution soil moisture distribution
• Test the feasibility of change detection algorithm

REMOTE SENSING DATA:
• ENVISAT/ASAR GM (2008-2011, HH, 1382 scenes)
• ERS 25km Surface soil moisture
• MODIS/Terra Snow Cover Daily L3 Global 500m Grid, Version 5
Dry Reference

Wet Reference

Dry Reference [dB]
- High: 4.48853
- Low: -9.6014

Wet Reference [dB]
- High: -4.89271
- Low: -21.0349

10 cm soil moisture observations at A'rou freeze/thaw observation station
ASAR GM estimated soil moisture at A'rou freeze/thaw observation station
Daily precipitation

RMSE (observed and estimated SM) = 0.11 cm³/cm³
Maximum estimation error of volumetric moisture [cm³/cm³]
- High: 0.116175
- Low: 0.0261078

result
Monthly mean of soil moisture (cm³/cm³) during 2008 ~ 2011 in the upper reach of the HRB

Monthly mean of soil moisture during 2008 ~ 2011

POSTER No. 34
2.3.2 Active and passive L-band microwave remote sensing for soil moisture – a test bed for SMAP fusion algorithms

Combination of PLMR2 and DLR F-SAR

F-SAR is able to operate in 4 frequency bands (X, C, L and P)
Dual (F-SAR) channel operation

Polarisation: Dual linear (V and H)
Incidence angles: +/- 8°, +/-22°, +/- 38° @ pushbroom

Germany
The Rur Catchment
Surface temperature  PLMR2 Tb  PLMR2 SM

- L-MEB radiative transfer model
- Utilizing LAI, soil map, surface temperature, ...
- Calculated on footprint level for different incidence angles with subsequent interpolation

Surface temperature}

[Images of temperature maps for IR, PLMR2 TbH, and PLMR2 SM]
Algorithm 1
Disaggregation of the radiometer soil moisture product (Das et al. 2011):

Algorithm 2
Disaggregation of radiometer brightness temperatures (Das et al. 2014):
2.3.2 Mapping soil moisture using PLMR observations in the HRB

Retrieval schemes:
- Multi-angular observations, TB+TIR
- L-MEB
- Single/multi-channel/parameter

H-polarization

V-polarization

Beam 3.4

Beam 2.5

Beam 1.6

LST
Li DZ et al., GRSL, 2015

Three channels retrieval result
2.4 Evapotranspiration

- Conducting a revised integration method to yield better ET estimates in irrigated farmlands in Zhangye Oasis of the Heihe River Basin
- Estimations of regional surface energy fluxes over heterogeneous oasis–desert surfaces
- Estimating and validating soil evaporation and crop transpiration
- A weak-constraint variational data assimilation (WC-VDA) scheme
2.4.1 Conducting a revised integration method to yield better ET estimates in irrigated farmlands in Zhangye Oasis of the HRB

<table>
<thead>
<tr>
<th>Date</th>
<th>Stable time</th>
</tr>
</thead>
<tbody>
<tr>
<td>20120710</td>
<td>11-16, 17.5</td>
</tr>
<tr>
<td>20120802</td>
<td>9-16, 17.5</td>
</tr>
<tr>
<td>20120811</td>
<td>9, 10-14.5</td>
</tr>
</tbody>
</table>

**Flowchart:**

1. Input data
2. EF$_{EC}$ keeps stable? NO: EF$_{ASTER}$ is replaced by EF$_{EC}$, YES: EF$_{ASTER}$ is optimized by $r$
3. NO: $\beta_{ASTER} > 1.5$? YES: EF$_{ASTER}$ is used in time scaling

**Table:**

<table>
<thead>
<tr>
<th>Date</th>
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</tr>
</thead>
<tbody>
<tr>
<td>20120710</td>
<td>11-16, 17.5</td>
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<tr>
<td>20120802</td>
<td>9-16, 17.5</td>
</tr>
<tr>
<td>20120811</td>
<td>9, 10-14.5</td>
</tr>
</tbody>
</table>
POSTER No. 36

<table>
<thead>
<tr>
<th></th>
<th>cEF</th>
<th>vEF</th>
<th>vEFr</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RMSE (mm d⁻¹)</strong></td>
<td>1.19</td>
<td>0.85</td>
<td>0.54</td>
</tr>
<tr>
<td><strong>MRE (%)</strong></td>
<td>19.97</td>
<td>12.77</td>
<td>7.26</td>
</tr>
<tr>
<td><strong>Corr.</strong></td>
<td>0.72</td>
<td>0.72</td>
<td>0.81</td>
</tr>
</tbody>
</table>
2.4.2 Estimations of regional surface energy fluxes over heterogeneous oasis–desert surfaces

Ma YF et al., GRSL, 2015
The revised SEBS model is appropriate for estimating regional energy fluxes over heterogeneous oasis–desert surfaces.
2.4.3 Estimating and validating soil evaporation and crop transpiration

Comparison of the estimated E/ET% and T/ET% values with the ground-based measurement data using the stable oxygen and hydrogen isotope technique.

The results show that even under the strongly advective conditions, the TSEB model produced reliable estimates of the E/ET% and T/ET% ratios and of ET.

Scatterplots of the comparison of the energy components derived from the TSEB model with the measurements from a four-component radiometer and an EC system.

Song LS et al., GRSL, 2015
2.4.4 A weak-constraint variational data assimilation (WC-VDA) scheme

The WC-VDA model was tested at two sites which represent typical desert–oasis landscapes in the middle reaches of the HRB. The results proved that the WC-VDA method performed well over very dry and wet conditions, and the estimated sensible and latent heat fluxes agree well with eddy covariance measurements.

Daytime-averaged turbulent heat flux estimates from model estimates (the solid line) compared with the ground measurements (the open circles) in the Daman and Huazhaizi sites

Xu TR et al., GRSL, 2015
2.5 Groundwater

- Using Gravity Recovery and Climate Experiment (GRACE) gravity satellite data to quantitatively investigate recent drought dynamic over arid regions of Northwest China
- Optimal selection of groundwater-level monitoring sites in the Zhangye Basin
2.5.1 Using GRACE data to quantitatively investigate recent drought dynamic over arid regions of Northwest China

Total storage deficit index (TSDI) of the arid land

Drought severity classification based on TSDI

<table>
<thead>
<tr>
<th>Class</th>
<th>TSDI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet</td>
<td>$1.0 &lt; \text{TSDI}$</td>
</tr>
<tr>
<td>Near normal</td>
<td>$-1.0 &lt; \text{TSDI} \leq 1.0$</td>
</tr>
<tr>
<td>Mild drought</td>
<td>$-2.0 &lt; \text{TSDI} \leq -1.0$</td>
</tr>
<tr>
<td>Moderate drought</td>
<td>$-3.0 &lt; \text{TSDI} \leq -2.0$</td>
</tr>
<tr>
<td>Severe drought</td>
<td>$-4.0 &lt; \text{TSDI} \leq -3.0$</td>
</tr>
<tr>
<td>Extreme drought</td>
<td>$\text{TSDI} \leq -4.0$</td>
</tr>
</tbody>
</table>

Cao YP et al., Remote Sens., 2015
Spatial distributions of TSDI-derived drought conditions and average TWSC in the arid land of northwestern China

(a) GRACE-TSDI
- Xingjiang
- Uygar
- Autonomous Region
- Inner Mongolia
- Hebei Corridor

Drought Severity
- Extreme drought
- Severe drought
- Moderate drought
- Mild drought
- Near normal
- Wet

(b) GRACE-TWSC
- EWH / mm
- -50 to -40
- -40 to -30
- -30 to -20
- -20 to -10
- -10 to 0
- 0 to 10

TSDI, SPI-3, and SPI-12

Cao YP et al., Remote Sens., 2015
Temporal distribution of Groundwater in the HRB

Seasonal variations of groundwater estimated by GRACE in the HRB divided by warm and cold seasons.

Spatial variation of monthly groundwater in the HRB.

Spatial variation of interannual groundwater storage in the HRB during 2003 - 2012.
2.5.2 Optimal selection of groundwater-level monitoring sites in the Zhangye Basin

This scheme integrates kriging theory and stratification techniques based on the assumption of a non-homogeneous groundwater-level spatial distribution. The temporal stability of the groundwater-level spatial pattern is considered a stratification in this scheme.

Ran YH et al., JH, 2015
The stratification for groundwater level monitoring site optimal selection according to the temporal stability of the groundwater level.

Table 1
The distribution of the new observation wells in different stability stratum.

<table>
<thead>
<tr>
<th>Stratification type</th>
<th>Num of existing well</th>
<th>Area (km²)</th>
<th>Num of new well</th>
</tr>
</thead>
<tbody>
<tr>
<td>High stability stratum</td>
<td>21</td>
<td>2259.24</td>
<td>5</td>
</tr>
<tr>
<td>Middle stability stratum</td>
<td>22</td>
<td>2531.06</td>
<td>14</td>
</tr>
<tr>
<td>Low stability stratum</td>
<td>8</td>
<td>1266.33</td>
<td>12</td>
</tr>
</tbody>
</table>

The relationship among the desired standard deviation, the number of added observation wells, and temporal stability.
2.6 Assimilating hydrological observations and products

- Multi-sources data assimilation system applied in the HRB; joint brightness temperature and surface temperature assimilation for Rur catchment (reported in 2014 symposium)

- Improving the estimation of hydrological states in SWAT model via ensemble Kalman smoother at basin scale

- Multivariate land data assimilation at global scale
2.6.1 Improving the estimation of hydrological states in SWAT model via ensemble Kalman smoother

Lei FN et al., AWR, 2014

Subbasins: 27
HRUs: 292
Assimilation results

Lei FN et al., AWR, 2014

RMSE

Surface soil water content

Profile soil water content

Evapotranspiration

Lateral flow

Lei FN et al., AWR, 2014
Global land data assimilation with community land model.
Difference of latent heat flux (upper) and runoff (lower) between data assimilation (ESA_SM-a,c or GRACE-b,d) and CLM Openloop simulation on 01-2009
Difference soil moisture at 10 cm (upper) and 50 cm (lower) between data assimilation (ESA_SM-a,c or GRACE-b,d) and CLM Openloop simulation on 01-2009
3. Sino-European Collaboration

YS exchange

Correction of systematic model forcing bias of CLM using assimilation of cosmic-ray Neutrons and land surface temperature: a study in the Heihe Catchment, China

X. Han\textsuperscript{1,2,3}, H.-J. H. Franssen\textsuperscript{2,3}, R. Rosolem\textsuperscript{1}, R. Jin\textsuperscript{1,5}, X. Li\textsuperscript{1,5}, and H. Vereecken\textsuperscript{2,3}
4. Summary and perspective

- The framework of data assimilation system has been established, and has been proven to be effective for both at basin and global scales.

- Basin scale remote sensing products of precipitation, ET, soil moisture, snow cover area, snow water equivalent, runoff, and groundwater storage having been further produced and evaluated.
Specific outlook

- Precipitation: to assimilate snow depth product into the WRF model to enhance solid precipitation simulation
- Soil moisture: to downscale coarse resolution SM product and to derive SM product using ASAR GM observations focused on the HRB; to investigate more fusion algorithms for active/passive microwave remote sensing observations and SM products
- ET: to integrate various research efforts to derive basin scale product
- Ground water storage: to use GOCE observations
- Data assimilation: LAI, SWE measurements and other sources of observations will be used in the data assimilation to improve the results
- Validation activities having been extensively conducted and will be more focused consistently.
4. Summary and perspective

- To deliver a set of reliable water budget components RSPs at basin scale with high spatial-temporal resolution.

- With these products and integrated study will facilitate the goal of closing water cycle and improve our understanding on basin scale hydrological cycle.
Publication list


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Email: h.vereecken@fz-juelich.de

Thank you!
METHOD:

- process ASAR GM using NEST
- angle normalization of ASAR GM backscattering
- determine the dry and wet reference for each basin grid
- estimate the relative soil moisture using the change detection method
- convert to volumetric soil moisture based on Van Genuchten Formula
Average latent heat flux of FLUXNET(MTE)-a, CLM Openloop simulation-b, data assimilation (ESA_SM-c or GRACE-d) on 01-2009