DROUGHT MONITORING AND DROUGHT PREDICTION IN CHINA USING REMOTE SENSING, LAND SURFACE MODELS (LSM) AND DATA ASSIMILATION: PRELIMINARY RESULTS OF THE LOESS PLATEAU FIELD EXPERIMENT IN 2005 (LOPEX05)

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ABSTRACT

Drought disasters have often caused great hunger, social instability, large scale migration of the population and the distinction of civilizations in the history. The conflict between supply and demand of water resources constitutes the biggest problem for food security of a huge population in China and drought has become a key factor constraining China's economic development.

The Dragon project "drought monitoring and drought prediction" will be used to develop a system to monitor and generate predictions of the soil moisture conditions in the root zone. The methodology that will be employed is based on the direct assimilation of satellite observation in a land surface modeling framework. The advantage of this methodology is that physically based methods can be used as compared to (semi-) empirical direct-retrieval algorithms.

Within the framework of this project a field campaign was held in the summer of 2005 near the city of Pingliang in Gansu province, China. The ground truth data set collected during this experiment consists of continuous time series of land surface radiation, water and heat fluxes and an extensive set of land surface parameter observations, such as soil moisture, Vegetation Water Content (VWC) and Leaf Area Index (LAI). In conjunction with the ground observations a series of EnviSat AATSR[1], ASAR[2] and MERIS[3] scenes have been requested. This data set will be used to develop the drought monitoring and forecasting systems. In this paper, some of the preliminary results from the ASAR and MERIS data sets are presented.

[1]AATSR ~ Advanced Along Track Scanning Radiometer
[2]ASAR ~ Advanced Synthetic Aperture Radar
[3]MERIS ~ Medium Resolution Imaging Spectrometer

1. INTRODUCTION

Food security is one of the biggest social-economical problems in the world and often causes political conflicts within and among countries. Often crop water availability is a major concern of farmers in non-irrigated agriculture. In China, approximately once every two years severe droughts occur and in most cases the area affected is larger than 33.3 million hectares and the annual loss of grain amounts to more than 10 billion kilograms. Within the framework of the European Space Agency (ESA)-National Remote Sensing Center of China (NRSCC) Dragon "drought monitoring and drought prediction" project a system will be developed to monitor and predict droughts based on moisture changes in the upper part of the soil layer. The monitoring component of the project will be based on the retrieval of land surface parameters using near real-time satellite observations acquired by the ESA Environmental Satellite (EnviSat). The prediction part will be achieved by assimilation of satellite retrievals in a Land Surface model (LSm).

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Remote sensing provides spatially distributed observations of the land surface. The remotely sensed reflectivity's are sensitive to states that relate to the vegetation and soil layer, such as vegetation water content (*VWC*), Leaf Area Index (*LAI*), surface temperature (T_s) and soil moisture. These characteristics have been used by various scientists to retrieve either these land surface variables [1-3] or to generate higher level products from the retrieval products [4-7]. For this study similar retrieval algorithms will be applied, and if necessary adjusted to develop a drought monitoring system for China. The Land Surface parameters that are of interest to this study are: root zone soil moisture, evaporation and vegetation parameters.

The root zone soil moisture content is an important state variable and is a good drought indicator. Under limiting soil moisture conditions the evaporation of crops is restricted and the yield is immediately reduced. However, under non-limiting conditions percolation to the groundwater occurs and river flow is generated. Remote sensing of soil moisture is being studied in several experiments [10] and by many investigators [11-13], but it has been very difficult to estimate the spatial and temporal variability of soil moisture using satellite observations [14].

Other drought indicators are, for example, the vegetation conditions and the actual evaporation. The state of the vegetation throughout a growing season is strongly influenced by the crop water availability. Satellite retrieved vegetation parameters contain information about the plant water availability. From remote sensing observations alone the actual state of the vegetation layer can be retrieved and assimilation techniques can be used to derive the root zone soil moisture content [8]. The uptake of soil moisture by crops is restricted by the soil water suction and constrains the portioning between latent and sensible heat fluxes. In this perspective, the remotely sensed latent heat flux is a measure for the crop water availability and can, thus, be used as a drought indicator [6]. Evaporation cannot be directly observed, but could be derived from satellite retrieved land surface parameters and meteorology data, such as surface temperature and vegetation parameters.

Within the framework of the Dragon drought project, a two-month field EXperiment was conducted in the Chinese LOess Plateau in the summer of 2005 (LOPEX05). The selected study area is located near the city of Pingliang in Gansu province, China. The objective of the LOPEX05 campaign was to collect ground truth observations for validation and development of land surface parameters and heat flux retrieval algorithms based on satellite observations. Soil moisture, temperature, Leaf Area Index (LAI) and Vegetation Water Content (VWC) measurements were made in conjunction with the satellite overpasses. In addition, meteorological flux towers were installed at three locations and provided continuous observation of the important energy balance components. This extensive set of ground and satellite observations will be used in this research. In this paper, the development of the drought monitoring methodology is discussed. Further, the data sets collected during the LOPEX05 experiment are described in detail and some preliminary results of the LOPEX05 fields experiment are presented.

2. DROUGHT MONITORING COMPONENT OF THE DRAGON PROJECT

In our research, a distinction is made between so-called states and process variables. State variables describe the dynamic properties of the land surface system and affect the magnitude of land surface processes, such as the partitioning of latent and sensible heat fluxes, and groundwater recharge. Satellite observations are capable of observing the states of the earth's surface and process variables have to be computed from the remotely sensed retrievals. As a result, the accuracy of modeled land surface processes is strongly related to the accuracy of satellite retrievals

More generalized methods are necessary to improve the accuracy of land surface modeling. Theoretical Radiative Transfer models (RTm), such as Scattering from Arbitrarily Inclined Leaves (SAIL) [16] and Michigan Microwave Canopy Scattering (MIMICS) [15] have been developed to simulate the satellite observations. These models have been successfully validated in small-scale experiments for a variety of surface conditions. A major drawback of most theoretical methods is the extensive parameterization required, which is typically not available on a global scale. Model inversion is inevitable, but a number of unknown parameters typically exceeds the available number of independent observations leading to ill-posed optimization schemes.

Space agencies acknowledge this problem and are continuously in the process of launching more advanced sensors, which are able to acquire more independent observations. In addition, advances in land surface modeling have demonstrated that the synergistic use of traditional LSm's, RTm, and satellite observations can improve hydrological and crop yield predictions [8]. The RTm's are used to simulate the canopy reflectance observed by satellite sensors based on a parameterization provided by the LSM's. Based on comparisons of the simulation results and satellite observed canopy reflectance in combination with statistical assimilation procedures, the state variables within the LSm are optimized. A schematic layout of this assimilation procedure is given in figure 1 and similar approaches have been frequently applied to optical and thermal observations [7, 9]. Incorporation of microwave data into the assimilation scheme has been limited to application of semi-empirical microwave scattering methods [8].

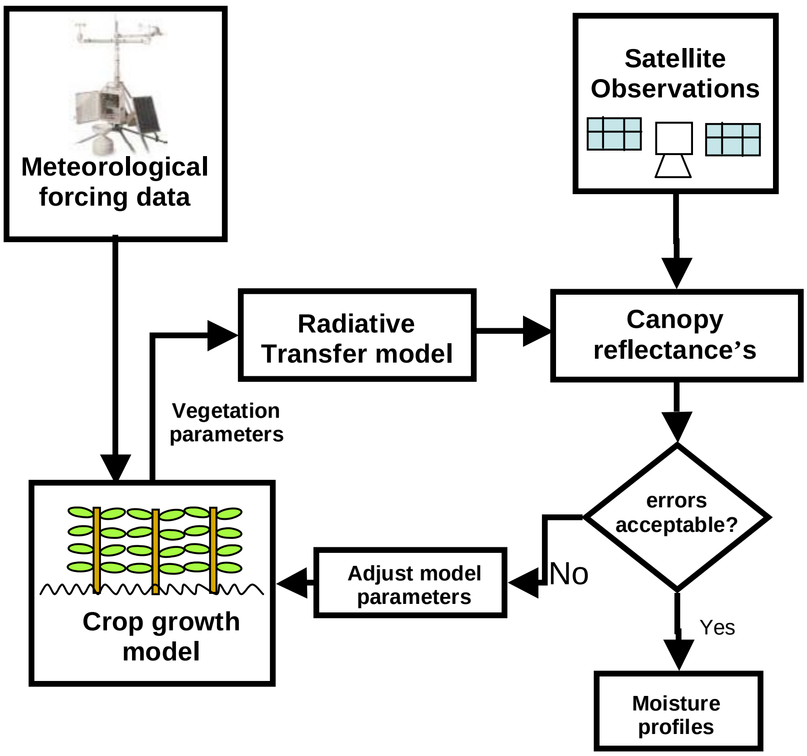

Figure 1: Schematic outline on the assimilation procedure that will be used for the retrieval of land surface parameters as a part of the drought monitoring system.

Drought monitoring in this research will be established through direct assimilation of the satellite observations into a modeling framework. A theoretical radiative transfer model will be used in a forward application for which a crop growth model will be employed to provide the vegetation parameterization required for RTm's. A combination of the Properties Spectra (PROSPECT) [17] leaf reflectance model and GeoSAIL [7] two layered canopy reflectance models will be used to simulate the satellite observations from the spectral range from 400 to 2400 nm. For the simulation of microwave observations, the coherent scattering model developed by Karam et al. (1992) [18] will be used. The data set collected in the LOPEX05 experiment will be used to validate this methodology in future studies.

3. LOPEX05 FIELD EXPERIMENT

The LOPEX05 experiment was conducted on the top of the loess plateau (mesa area) near the city of Pingliang in Gansu province, China. The selected area is characteristic for the Chinese Loess Plateau, which is a typical terrace landscape formed through fluvial erosion. The mesa area is located approximately 1500 meters above sea level and is primarily used for agricultural purposes. Corn, millet and winter wheat are the dominant crop types. The hill slopes consist of abandoned farmlands and are now covered by shrubs and grass. The valley is imbedded in the landscape about 300 to 400 meters below the peaks of the plateau, where corn and millet are the dominant crop types. Heat, water fluxes and land surface parameter measurements were collected on the plateau and in the valley.

During the two-month Intensive Observation Period (IOP), heat and water fluxes observations were collected continuously using three eddy correlation systems (ECS) and one automated weather station (AWS). Two ECS's and the AWS were installed on the mesa, and the third ECS was stationed in the valley. Each ECS was equipped with a 3D-sonic-amonemeter, a kip&zonen net radiometer, humidity equipment and four TDR probes installed at depths of 2.5, 10, 20 and 40 cm. The AWS consists of basic meteorological instrumentation such as humidity, wind speed and direction.

Intensive ground sampling strategy was conducted on clear days and included soil moisture, Leaf Area Index (LAI), Vegetation Water Content, temperature and some basic geometric measurements of the canopy layer (i.e. crop height, number of leaves). The sampling transect covered of eleven sites, of which five sites were located on the plateau and the other sites were situated in the valley. At each sampling location one set of measurement was acquired over a bare soil surface and another set over a vegetated area next to a bare soil field (millet or corn). In figure 2 an ASAR image acquired on 28th of July, 2005 over the LOPEX05 study area is shown and the approximate locations of the experimental sites are added.

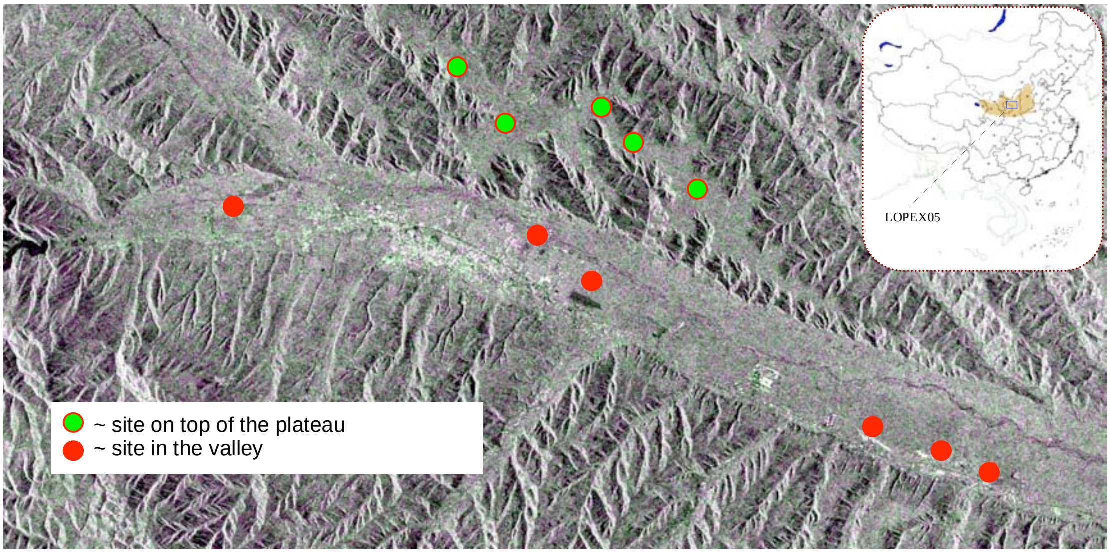

Figure 2: A HH/VV-polarized ASAR image (IS5, with central incidence angle of 38 degrees) of the LOPEX05 study area in which the sampling locations are indicated. The HH-polarized band is projected in the red and blue bands, and the VV-polarized channel is presented in the green band.

Soil moisture was measured using gravimetric and impedance probe techniques. The hand-held Stevens hydra-probe was used to collect capacitance observations over a soil depth of 6 cm. A scoop tool was used to extract soil samples of 6 cm depth, from which the gravimetric moisture content can be obtained using an oven-drying method. The gravimetrically derived soil moisture measurements are taken to calibrate the hydra-probe dielectric observations. However, due to time constraints, the hydra-probe observations have not been calibrated yet. Therefore, the soil moisture measurements presented in this paper are derived from the gravimetric samples.

A portable LICOR LAI-2000 Canopy Analyzer was used to collect spectral observations over the vegetated study sites, which are converted into Leaf Area Index (LAI) values. At each vegetated experimental field two sets of spectral measurements were made resulting in two LAI values. The average of these two values is used in the analysis.

4. SATELLITE OBSERVATIONS

In the framework of the LOPEX05 field campaign, a series of 10 ASAR Alternating Polarization (AP) and 15 MERIS full resolution images has been received. The ASAR instrument is the first dual-polarized C-band (5.3 GHz) radar instrument mounted on a satellite platform. Compared to the predecessors onboard the ERS-1/-2 platforms, two new features have been added to the high resolution mode. The viewing angle of the ASAR antenna can be set between 15 and 45 degrees and dual-polarized observations (HH/VV, HH/HV and VV/VH) can be acquired. For the LOPEX05 experiment, multiple HH/VV-polarized AP images in ascending and descending passes have been requested in the IS1, IS2, IS5 and IS7 image swath modes, which correspond to central incidence angles of 19, 23, 38 and 44 degrees, respectively.

The MERIS instrument is an imaging spectrometer designed to acquire data at a variable band width (1.25 – 30.0 nm) over a spectral range of 390-1040 nm [19]. The spectrometer has 15 bands that can all be programmed in width and centre wavelength. The standard band setting of the MERIS instrument and the potential application of each band is given in table 1. The MERIS instrument can operate in reduced resolution or in full resolution mode acquiring surface reflectance at resolutions of 1.2 km and 300 m, respectively.

Table 1: MERIS spectral bands in standard setting and their potential application [19].

Band	*Wavelength centre (nm)*	*Bandwidth (nm)*	*Potential application*
1	412.5	10	Yellow substance, turbidity
2	442.5	10	Chlorophyll, absorption maximum
3	490	10	Chlorophyll, other pigments
4	510	10	Turbidity, suspended Sediment, red tides
5	560	10	Chlorophyll reference, suspended sediment
6	620	10	Suspended Sediment
7	665	10	Chlorophyll absorption
8	681.25	7.5	Chlorophyll fluorescence
9	705	10	Atmospheric correction, red edge
10	753.75	7.5	Oxygen absorption reference
11	760	2.5	Oxygen absorption R-branch
12	775	15	Aerosols, vegetation
13	865	20	Aerosols corrections over ocean
14	890	10	Water vapor absorption reference
15	900	10	Water vapor absorption, vegetation

In this study, the sensitivity of the ASAR backscatter measurements to the gravimetrically derived soil moisture is explored using the data sets acquired during the ascending passes. The spectral surface reflectance computed from MERIS observations are compared to the ground based LAI measurements made during the experiments. For the development of the drought monitoring and drought prediction system, these results will be taken into consideration.

5. PRELIMINARY RESULTS

Simultaneous to the in-situ soil moisture measurements, multiple ASAR alternating polarization images with various image swaths have been acquired in descending as well as ascending satellite passes. Since the influence of the incidence angle on backscatter observations (σ^o) is only partly understood, the backscatter measurements can be compared with each other when they are acquired in the exact same configuration (i.e. incidence angle and pass). Unfortunately, at the time of this writing, not all requested images have been received. Therefore, the presented analysis is restricted to a simple comparison of the σ^o sensitivity to soil moisture observed for the different Image Swath modes. The date of acquisition and incidence angle of the used scenes are listed in table 2. Further, due to calibration problems of the capacitance observations, the soil moisture measurements used for this study are derived from gravimetric samples, which have not been collected on every sampling day for each site.

Table 2: List of ASAR HH/VV polarized scenes acquired in an ascending satellite pass.

Date of acquisition	Image Swath (IS)	Incidence angle range (degrees)
2005/07/22	IS2	19.2 - 26.7
2005/07/28	IS5	35.8 - 39.4
2005/07/31	IS7	42.5 - 45.2
2005/08/07	IS1	15.0 - 22.9

The σ^o observations are extracted from each of the scenes and averaged per sampling location. In figure 3, the averaged HH and VV-polarized radar responses are plotted against the ground observed soil moisture values. Despite the somewhat scattered distribution of data points, a positive relationship between σ^o and soil moisture can be observed. The incidence angle, however, appears to have a strong influence on the σ^o response to changes in soil moisture. At low viewing angles of nadir (IS1 and IS2), the range in σ^o is wider than at higher viewing angles (IS5 and IS7).

Radar observations acquired at low viewing angles typically have a higher σ^o response to changes in soil moisture, but the backscatter response is also sensitive to variations in other land surface parameters, such as surface roughness, vegetation geometry and vegetation density [20]. At higher viewing angles, the radar sensor observes a large vegetation volume, which often saturates C-band observations [21]. The soil moisture sensitivity of σ^o observed at large viewing angles originates from vegetated-soil surface interactions, which is a first-order scattering term and is small compared to the zeroth order surface and vegetation scattering terms [22]. Consequently, the σ^o sensitivity to changes in soil moisture is lower for observations made at high viewing angles [21].

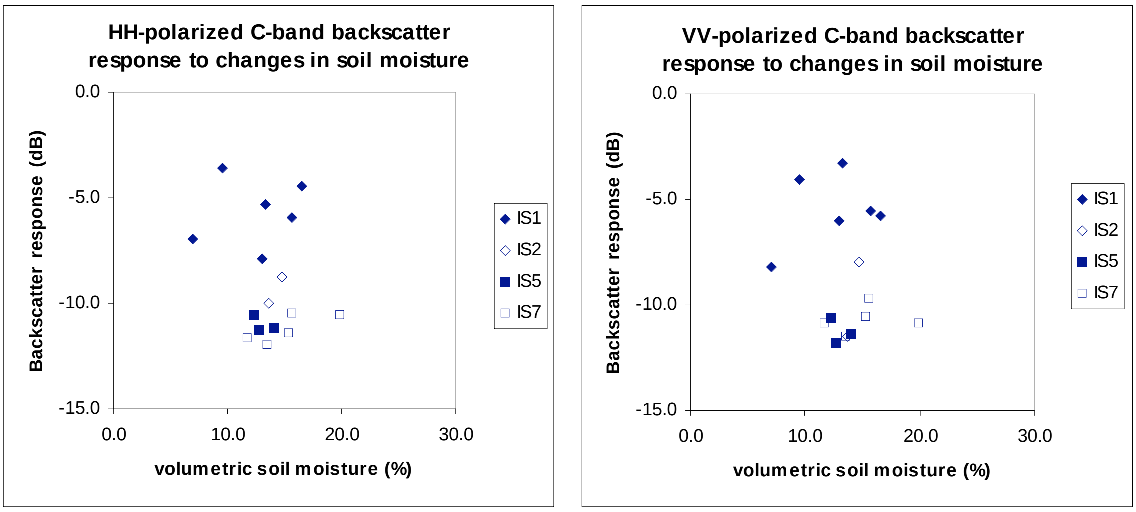

Figure 3: ASAR HH-and VV-polarized backscatter values acquired at different viewing angles plotted against volumetric soil moisture derived from gravimetric soil samples.

Within the IOP of the field campaign, all available MERIS full resolution scenes were requested. However, because optical satellite observations are obscured by clouds, only a limited of number scenes provided useful cloud free data. Figure 4 shows a selection of three cloud free false color MERIS images that have been geocoded and atmospherically corrected using the Basic ERS & Envisat (A)ATSR and Meris

(BEAM) Toolbox. The increasing density of red colors in the series MERIS images illustrate that further in the growing season the vegetation biomass increases.

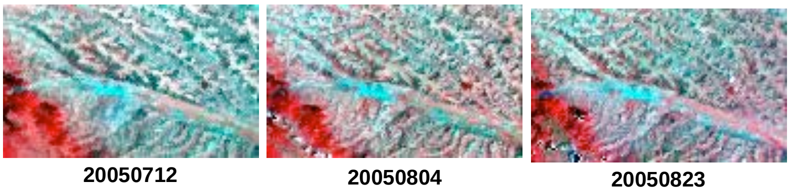

Figure 4: A series of MERIS false color image acquired over the LOPEX study area, in which the spectral bands 13, 8 and 5 are displayed in red, green and blue, respectively.

The sensitivity of the MERIS reflectance observations is further explored by comparing the reflectance observations with the LAI measurements. Figure 5, reflectance's observed in band 5, 12 and 15 are plotted against the LAI observed with the field spectrometer. The sensitivity of the reflectances to changes in vegetation biomass is very weak. However, it is difficult to draw conclusions from this figure because the resolution of the MERIS products is 300 meters, while agricultural fields in this area are approximately 10 meters wide and up to 100 meters long. Using a data assimilation system, such as employed by Verhoef and Bach [7], probably more information can be retrieved from the series MERIS images.

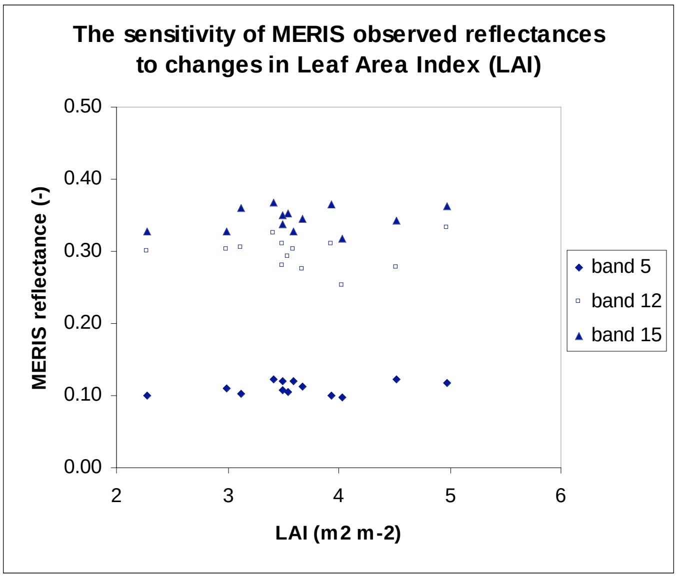

Figure 5: geocoded and atmospherically corrected MERIS reflectances plotted against ground measured LAI values.

6. SUMMARY

Within the dragon drought monitoring and drought prediction project, a system will be developed to monitor and generate predictions of the root zone soil moisture conditions. Direct assimilation of satellite observations into a Land Surface modeling system will be used to obtain estimates of the land surface state variables. The advantage of this methodology is that theoretically based models can be used over the semi-empirical satellite retrieval algorithms.

In this paper, some preliminary results of the ASAR and MERIS data sets have been presented. The ASAR backscatter observations show some response to changes in the soil moisture content measured in the top 5-cm soil layer. The interpretation of the MERIS reflectance measurements is more complicated because of the rather coarse resolution cells (300 m) within a rather heterogeneous study area. In the near future, more detailed investigations will be conducted to explore the full potential of the ground truth and satellite data sets within a data assimilation modeling framework.

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