INTERNATIONAL EARTH OBSERVATION INITIATIVES AND PROGRAMS: THE CONTEXT FOR GLOBAL URBAN MAPPING

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ABSTRACT:

Besides the dominant focus of urban remote sensing research on local and regional scales, the URS2005 conference offers a special session on "Global Observation of Urban Areas". This session was jointly initiated by the GOFC-GOLD (Global observations of forest and land cover) emphasizing that coordinated, consistent, and operational urban mapping and monitoring has to consider the evolving efforts in international coordination and cooperation for land observations at global scales. Recent developments again emphasize the need for sustained, harmonized, and validated earth observation products, i.e. in UNCED's Agenda 21, UNFCCC and the Kyoto protocol, the World Summit on Sustainable Development (WSSD) in Johannesburg 2002 and the related Group of Earth Observations (GEO) formed in 2003 that has evolved to a Global Earth Observation System of Systems (GEOSS), the European Global Monitoring for Environment and Security (GMES) initiative, as well as, the GCOS implementation plan calling on land cover. These developments aim at long term goals but have to start and evolve from an international cooperation and consensus building efforts, both in on the strategic level and in implementation activities. These developments will set the frame for global urban observations with its main focus on continuity and consistency in earth observations that best fits user requirements.

1. INTRODUCTION

The persisting dynamic urban change processes, especially the tremendous worldwide expansion of urban population and urbanized area, affect and drive natural and human systems at all geographic scales. Urbanization is the trigger for a variety of other land change processes in natural and semi-natural environments. Any operational efforts tailored at sustainable and desirable future development have to consider urban dynamics as one of the key human-induced processes for understanding and managing our fast changing world.

Earth observation has been focused on mapping, monitoring and understanding these urban phenomena for many years, however, with more emphasize on local to regional scales. Global mapping of human settlements faces particular challenging due to spatial and spectral heterogeneity of urban environments, as well as, their small and fragmented spatial configuration. In fact, there is large disagreement between urban land represented in different global land cover products (Fig.1, see also Schneider et al., 2003). Different reasons can be mentioned: challenges in mapping urban areas with coarse scale earth observation systems, different definitions of "urban" and varying mapping standards, issues with integrating different data sources, problems in precise geo-location of spatial datasets, and the importance of up-date information since urban areas are quickly evolving. Thus, global urban mapping can, in most cases, currently only marginally deliver what is needed to approach the multitude of challenges resulting from continuous urbanization and population growth.

The recent proliferation of new sources of data and tools for data processing, analysis and modeling has provided and opened up avenues for significant progress towards global observations of urban patterns and dynamics. Due to the heterogeneity of global urban characteristics, the key issue is to combine earth observation indicators for characteristics and change in human settlements. Sensors like MODIS or LANDSAT give spectral evidence for built-up areas and the land cover configuration within urban environments; night-time observations by DMSP are a strong indicator of populated areas and population distribution; SAR measurements emphasize the three-dimensional characteristics of urban surfaces; thermal IR data contain information about energy fluxes and local climatic conditions.

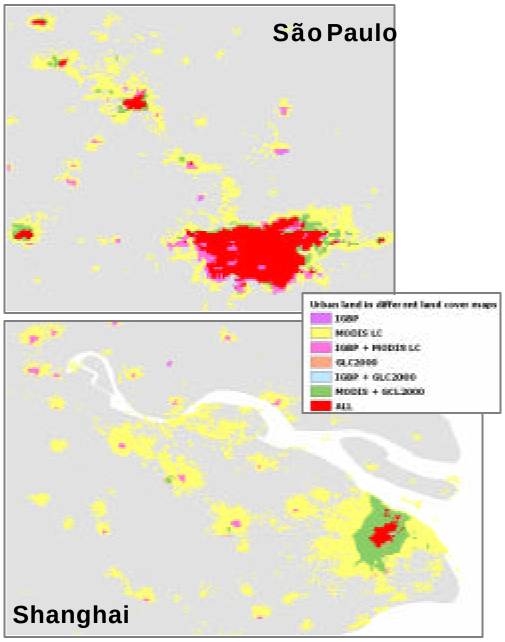

Figure 1: Comparison and agreement of urban land in three different global land cover products: IGBP DIS (urban areas from Digital chart of the world), MODIS land cover (urban areas from MODIS (2000), DMSP (1994/95) and ancillary data), and GLC2000 (urban areas from DMSP (1994/95)).

Other key projects and programs have been looking at representative urban agglomerations world wide to monitor spatio-temporal urban dynamics. The overall goal of earth observation is the mapping, monitoring, and analysis of urban form and processes towards support and improvement of urban modeling, management and planning efforts, and advances in understanding urban phenomena. Sustainable development activities benefit from the resulting better data, knowledge, and information, if the integrated framework includes a better integration and communication of the earth observation results, and works towards general acceptance of new and innovative techniques in approaching urban dynamics.

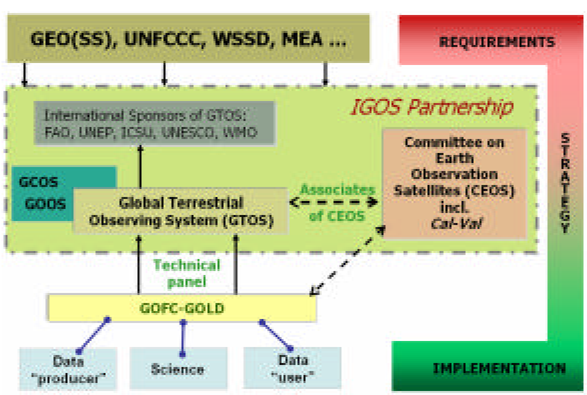

Figure 2: The "big picture" in global earth observations: organizations and agencies involved in defining requirements, strategies and implementation activities.

In parallel to developments of data availability and scientific research on their analysis, integration, and application, several international earth observation initiatives are currently evolving. The general goal is continuity and consistency in providing high quality data in support of sustainable and desired future development. GOFC-GOLD (Global observations of forest cover and Global observations of land dynamics, http://www.fao.org/gtos/gofc-gold) is technical panel of Global Terrestrial Observing System (GTOS, http://www.fao.org/gtos) and provides the interface between the strategic and the implementation level. GOFC-GOLD provides a communication and cooperation platform for actors involved in global earth observation including data producers (e.g. space agencies, land cover facilities), the scientific community, and data users (FAO, UNEP, global modeling community etc.). As part the activities, GOFC-GOLD jointly organized a special session on "Global Observations of Urban Areas" at the URS2005 conference. The overall goal of this special session is to provide a forum for researchers to communicate and discuss issues and challenges in coarse scale urban mapping and monitoring with respect to the recent strategic developments in the global earth observation arena. The aim of this paper is to provide an overview of current strategic developments and their requirements, and a summary of previous global urban mapping and monitoring activities and related challenges to set the frame for the special session and related discussions.

2. INTERNATIONAL LAND OBSERVATION INITIATIVES AND PROGRAMS

This section describes the main strategic developments and documents on global earth observations of land that have become available or started with the last year. Previous activities, e.g. the CEOS Global Urban Monitoring by the Working Group on Information Systems and Services (WGISS), are not described. Thus, all the described initiatives are very active and emphasize the importance of earth observation as basis for accurate and timely land surface data on global scales. These current activities show that there many activities that ultimately result further improvements in the global earth observation arena.

2.1 Group on Earth Observation (GEO) and the Global Earth Observation System of Systems (GEOSS)

The Group of Earth Observations (GEO, http://earthobservations.org/) was a direct follow up of the World Summit on Sustainable Development held 2002 in Johannesburg that called for strengthened cooperation and coordination among global observing systems and research programmes for integrated global observations. GEO emerged in 2003 from a consensus among governments and international organizations that, while supporting and developing existing Earth observation systems, more can and must be done to strengthen global cooperation and Earth observations. The GEO vision was formulated in the Washington Declaration adopted at the Earth Observation Summit of 2003. Since this declaration in

2003, the GEO process has resulted in a variety of Earth Observation Summits, the latest 6th Group on Earth Observations meeting took place in Brussels, Belgium on 14-15th February 2005.

The GEO process has outlined a framework document calling on Global Earth Observation System of Systems (GEOSS). While not legally binding, this document marks a crucial step in developing the 10-Year Implementation Plan for the creation of a comprehensive, coordinated, and sustained Earth observation system or systems.

Table 1: GEOSS earth observation objectives for urban mapping on global scales

Societal benefit area	Global earth observation requirements referring to urban areas
Disasters	Human infrastructure
Health	Urban heat island and air quality Population density Land cover
Energy	Land use and land cover Urban extent
Climate	Land cover
Water	Land use Industrial water demand Population density
Ecosystems	Population density
Agriculture	Land cover Population density

Given the current draft of the GEOSS implementation plan (Dec.2004) global urban mapping is mentioned in several circumstances (Table 1). Several aspects of urban mapping are described that several areas of societal benefit. It should be noted that some of these observation requirements are benefitial to several of these areas and are not mentioned twice. Urban extent and land use/land cover maps are considered to be not yet widely available or not yet adequately monitored globally but could be within two to ten years. One parameter not mentioned in Table 1 is transportation infrastructure that also is called on in the GEOSS implementation plan.

Most of the urban mapping features (e.g. urban extent, land use and land cover etc.) are considered to be not yet widely available or not yet adequately monitored globally but could be within two to ten years. The GEOSS plan also emphasizes the need for integrative analysis of the earth observation mapping products, i.e. gaps exist in the integration of relevant existing observation systems, for example, integrating the global urban land observations with data that characterizes the built environment, chemical emission, and with indicators of environmental quality, health and disease. Transportation infrastructure is also mentioned as additional mapping objective with a strong link to urban areas.

2.2 Integrated Global Observations of Land (IGOL)

The Integrated Global Observing Strategy (IGOS http://ioc.unesco.org/igospartners/) has been established in 1998. Its main objective is the definition, development and implementation of an Integrated Global Observing Strategy. IGOS brings together efforts of a number of international agencies concerned with global environmental issues, research, and observing systems. IGOS theme documents are a primary source of requirements for the development of GEOSS. However, the IGOS-Partnership (IGOS-P) has not yet considered many observational needs relating to many aspects of the land, such as sustainable economic development, natural resources management, conservation and biodiversity, ecosystems (functioning, services), biogeochemical cycling, multilateral environmental agreements (development, implementation), mandatory reporting and monitoring. A new IGOS theme is currently being proposed on Integrated Global Observations of the Land (IGOL). The main components of the new theme are: land cover and land use, human settlement and population, managed ecosystems, agriculture, pastoralism, forestry, natural ecosystems, conservation, biodiversity, sustainable use, soils, biogeochemical cycles, and elevation.

In terms of global urban mapping, IGOL emphasizes the need of coordinated global urban observations with the fundamental focus on reliable and spatially explicit settlement and population databases, transportation infrastructure information, and understanding urban change processes. Furthermore, there are plans for an IGOS working group specifically tailored at socio-economic data issues relevant to IGOS themes.

2.3 Global Monitoring for Environment and Security (GMES)

The objective of this initiative is to "establish by 2008 a European Capacity for Global Monitoring of Environment and Security (GMES)" (http://www.gmes.info). GMES, as joint initiative of the European Commission and the European Space Agency (ESA), aims to support Europe's goals regarding sustainable development and global governance, in support of environmental and security policies, by facilitating and fostering the timely provision of quality data, information, and knowledge. As part of the GMES an "Urban Services" section (http://www.gmes-urbanservices.com/) has been established. The objectives do not especially refer to global scale urban mapping. GMES priorities in urban mapping are set on local and regional scales to assist urban management and security.

2.4 Millennium Ecosystem Assessment (MEA)

The Millennium Ecosystem Assessment (MEA, http://www.millenniumassessment.org/) is an UN initiated international work program designed to meet the needs of decision makers and the public for scientific information concerning the consequences of ecosystem change for human well-being and options for responding to those changes. Being tailored at ecosystems, the observation requirements focus on mixed patterns of human use and ecosystems which emphasizes on the spatial extent of urban areas. A further focus is on urbanization processes and population growth as driver of ecosystem change on different spatial and temporal scales.

2.5 Global Climate Observing Systems (GCOS) implementation plan

In support of the United Nations Framework Convention on Climate Change (UNFCCC), the Global Climate Observing System (GCOS, http://www.wmo.ch/web/gcos/gcoshome.html) has completed an implementation plan in October 2004 to outline the requirements and actions to provide appropriate data base in the implementation of the UNFCCC objectives and the Kyoto protocols. The focus of this implementation plan is on climate but specifically calls on land cover and changes (and use) as important terrestrial variable to be derived from earth observation.

2.6 GTOS-Coastal implementation plan

The GTOS implementation plan on coastal zones (http://www.fao.org/gtos/doc/pub36.pdf) emphasizes the importance of urban areas in this environment since about half of the world population lives within 200 km from the coast. The IGOS Coastal theme already puts a priority on urbanization in coastal zones. Coastal GTOS implementation plan specifies several aspects, i.e. the rate of change in population, urbanization, and land use in coastal environments. The report discusses "best available global datasets" and their current limitations and prospects including the DOE Landscan Ambient Population, the DMSP Night-time data, the global Landsat mosaics, the ESA GLOBCOVER product and the MODIS land cover/urban product and vegetation continuous fields datasets.

2.7 UN Global Land Cover Network (GLCN)

The Global Land Cover Network (GLCN, ftp://ftp.fao.org/docrep/fao/004/y3726e/y3726e00.pdf) launched by FAO and UNEP, is an international coordinated effort with the objective to provide direction, focus, guidance and standards for harmonization of land cover mapping and monitoring at national, regional and global levels. The initiative is based on the recommendations of the Agenda 21 for coordinated, systematic and harmonized collection and assessment of data on land cover and environmental conditions. GLCN aims at generating essential data needed for sustainable development, environmental protection, food security and humanitarian programmes of the United Nations, and of other international and national institutions. The major objectives of this initiative are on harmonization and standardization of classification of cover types, the determination patterns of land-cover and its associated change, projections of human response scenarios, support to integrated global and regional modelling and the global assessment of land cover for international conventions and treaties. The GLCN strategic documents are currently in development and will also address issues of urban mapping and monitoring and related expectations for earth observations, and standardized mapping using the FAO Land Cover Classification System (LCCS).

3. GLOBAL MAPPING AND MONITORING ACTIVITIES

Previous global activities have applied a variety of data sources, mapping and monitoring strategies and analysis methods to study urban phenomena on gl obal scales (Table 2). The most comprehensive information on global urban dynamics has been derived from statistical datasets describing demographic, socio-economic and economic indicators of urban characteristics and quality. On global scales, this information usually exists in rather coarse spatial precision, with large time steps for updating, and sometimes the data are not consistently available for specific regions (e.g. developing countries). More detail can be provided by earth observation. Remote sensing data sources for coarse scale urban mapping have been multifaceted: optical data (Schneider et al., 2003), thermal measurements (Hafner and Kidder, 1999), active Radar data (Henderson and Xia, 1997, Grey et al., 2003), and night-time-lights DMSP data (Imhoff et al., 1997, Henderson et al. 2003). The data sources have been used to study a variety of urban phenomena like urban ecosystems (Miller and Small, 2003), urban climates (Voogt and Oke, 2003), urban population (Sutton et al., 1997, Small, 2003, Liu et al., 2005), health and disease (Tatem and Hay, 2004), urban growth and change processes (Phinn et al., 2002, Seto and Kaufmann, 2003, Herold et al., 2003) and others. So far, comprehensive global urban monitoring programs have been using selected representative cities. These urban areas are monitored in high spatial and temporal detail. The observations and analysis provide general assumptions about ongoing processes on coarser scale (Lavalle, et al., 2001, Beckel et al., 2002).

4. CHALLENGES FOR GLOBAL URBAN OBSERVATIONS

The initiatives presented in the previous sections emphasize that basic global urban information is still lacking. The best strategy to overcome these limitations are coordinated international mapping and monitoring efforts which include earth observations as central data source. To be successful, different challenges are mentioned in the strategic documents.

Despite a focus on global observations to data products have to be derived, analyzed, and refined a multi-scale context. Urban phenomena can be observed and show specific characteriscs on different levels of spatial and temporal and detail. Linking coarse scale (250-1000 m spatial resolution), fine-scale (20-50 m) and very fine-scale (1-4 m) and in-situ observations should be central perspective in any related activities. Continuity in earth observations on all these scales are essential to support such progress. Currently, coarse scale observations are widely available (e.g. MODIS, MERIS, SPOT VEGETATION) and will so in the future with systems like NPOESS. This level of continuity does not exist for the other scales.

As much as spatial and temporal detail, the issue of thematic and semantic accuracy will be of particular importance. In urban mapping (and other fields) data products are often produced as independent datasets with its individual semantic definitions. Issues of harmonization, interoperability, and synergy between different data sources and mapping products are important more than ever. This includes the standardized development of legends (e.g. using the FAO Land Cover Classification System) and flexible thematic definitions (e.g. through continuous rather than discrete mapping products, i.e. urban – rural gradient). Also, interoperability and application in general assumes that mapping products are independently validated.

Another essential requirement is the integration of the earth observation mapping and monitoring products with existing socio-economic/demographic information. These data are usually non-spatial data or spatially aggregated. An integration framework is presented in Figure 3. Earth observation measures urban characteristics "bottom up" describing the outcome of various processes at work (from structure to process). Socio-economic drivers or specific urban models usually follow a "top-down" approach by studying a pre-specified process of urban change and the resulting spatio-temporal patterns (from process to structure). Linking these two using spatial urban theory, spatial analysis and modeling provides an appropriate framework for monitoring, understanding, and modeling urban phenomena. This information is essential to anticipate and forecast future changes or trends of development, describe and assess economic, ecological, and social impacts of urbanization. Ultimately, an comprehensive integration framework will help building the bridge between observation and use and help to develop a common suite of urban indicators and information that use useful to use and support explore different policies and scenarios in support of planning and management decisions.

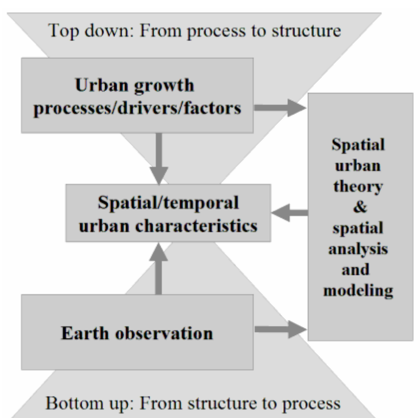

Figure 3. Conceptual framework for integration of earth observation data and drivers and factors of urban processes.

5. FOCUS OF THE SPECIAL SESSION

With the special on "Global observations of urban areas" the URS2005 conference, GOFC-GOLD is seeking input and discussions to approach these challenges. The science community is invited to provide input and evaluate strategies to further improve global urban observations. The themes for this special session reflect the recent developments and requirements:

- Tools and methods for mapping and monitoring urban areas on global scales
- Urban areas and global land cover products
- Global trends of urban development from earth observation
- Drivers/factors influencing global urban dynamics
- Integration of earth observation data in coarse scale urban modelling
- Economic, ecological and social impacts of urban development
- Forecasts of future urban developments and prospects in observing urban processes

Table 2: Overview of prominent urban mapping and monitoring initiatives and projects with focus on global/regional scales

Name	Objective	Data	Internet
Defense Meteorological Satellite Program - DMSP	Production of a city lights data base to map and monitor a variety of human and urban phenomena including urban extent and population density	Three of the four satellites in the Defense Meteorological Satellite Program (DMSP) record night-time data with unique capabilities to detect low levels of visible - near infrared (VNIR) radiance at night (i.e. lights from cities). The main Nighttime Lights of the World data set was compiled from the October 1994 – March 1995.	http://dmsp.ngdc.noaa.gov/
MODIS Land Cover Products – urban extent	Assess the utility of MODIS 1 km data for global urban mapping and derive and evaluate a map of urban extent for cities worldwide. The overall goal is to assess the role of urbanization as component of global change.	Mapping is based on MODIS data, DMPS city lights data and the gridded population of the world. The urban extent is part of MODIS 1 km land cover product using the IGBP legend of 17 classes.	http://duckwater.bu.edu/urban/global.html
Digital Chart of the World - DCW	Global data product of the Environmental Systems Research Institute, Inc. (ESRI) originally developed for the US Defense Mapping Agency (DMA).	Populated places are derived/digitized from DMA data sources, i.e. aeronautical charts (ONC) developed 1950-70ies.	http://www.maproom.psu.edu/dcw/
Urban Environmental Monitoring - UEM	Timely and continuous monitoring of rapidly urbanizing regions using EOS (and other) remotely sensed datasets with focus on mapping and modeling of urban/peri-urban biogeophysical and climatic properties (both current and historic) that are impractical to obtain using field-based studies. The information will be used for mapping and modeling to advance the understanding of urban development trajectories and urban „futures"	ASTER, MODIS, and Landsat MSS/TM/ETM+ data together with ancillary spatial and social information are used to assess urban processes.	http://elwood.la.asu.edu/grsl/UEM/
Megacities/ Eurocities	The project aimed to demonstrate the operational applicability of ERS-SAR data for the mapping of Megacities and Eurocities in combination with additional information from other Earth Observation systems or GIS data to support integrated management of planning and environmental issues that are central to urban decision-making, including topics such as noise, energy efficiency, city modelling and control of the urban sprawl.	The demonstration uses ERS-SAR coherence and intensity data combined with NDVI data from Landsat TM or ETM and additional GIS data	http://www.esa.int/esaCP/index.html
Monitoring Urban Dynamics – MOLAND / MURBANDY	To provide datasets to study past and current land uses, to develop an Earth Observation based procedure to monitor the dynamics of Europe's cities; to develop a number of "urban" and "environmental" indicators that allow to understand these dynamics and the impact these cities have on the environment, and finally to elaborate scenarios of urban growth	Creation of detailed GIS data SETS of *land use types* and *transport networks* for several study areas, at a mapping scale of 1:25,000, typically for four dates (early 1950s, late 1960s, 1980s, late 1990s) or for two dates (mid 1980s, late 1990s) in case of larger areas. The reference land use database (typically years 1998-2000) is created from interpretation of satellite imagery, most commonly from IRS satellite, and in few cases from the IKONOS or SPOT satellites. Historical data sets used additional data sources.	http://murbandy.sai.jrc.it/
Gigalopolis	Aims to extend and refine the Clarke urban growth model (SLEUTH) enabling predictions at regional, continental and eventually global scales	SLEUTH model requires input of five types (historical land use and urban development, topography, transportation networks, exclusion and hillshade, that are compiled and evaluated in several study areas worldwide.	http://www.ncgia.ucsb.edu/projects/gig/
Gridded Population of the World - GPW	Provide estimates of the population of the world in 1990 and 1995, both population counts (raw counts) and population densities (per square km). National figures have been reconciled to be consistent with United Nations population estimates for those years, unadjusted data are also available.	Count, density and area grid data for the world in several formats.	http://sedac.ciesin.org/plue/gpw/index.html?main.html&2
Global Urban Observatory Database - GUO	Addresses the urgent need for a world-wide base of urban knowledge by helping Governments, local authorities and organizations of the civil society develop and apply policy-oriented urban indicators, statistics and other urban information.	Human Settlements Statistics Database, Data House Version 2 2001 Database, City Profiles: 2001 Database	http://www.unchs.org/programmes/guo/default.asp

The outcomes of this special session will hopefully results in a synthesis describing prospects and scientific perspectives of global urban observations that can used by organizations like GOFC-GOLD to guide their future directions and efforts.

6. SUMMARY

Urban areas and their dynamics are one of the main drivers of land change on local to global scales. With small and fragmented spatial and spectrally heterogeneous characteristics, their accurate mapping and monitoring has been challenged in the past and certainly has not received as much attention as the global observation of other land types such as forests. Urban mapping requires different earth observation data sources and satellite data analysis approaches than suitable for other land surface types.

Different initiatives have provided interesting experiences and explored different strategies for assessment of urban change on global scales. The recent development in the strategic Earth Observation arena specifies the requirements and expectations for global urban monitoring programs. There is consensus that a comprehensive and sustained global urban observatory has to be built on coordinated international actions. Data products have to be harmonized, accessible, validated, and flexible to provide a better match between observations, data products, and user requirements, i.e. as outlined in the UN strategic documents.

The establishment of a global urban observatory provides great opportunities to establish successful cases for data integration that is desired in many fields of global earth observation. Synergy of satellite data from different sensors (DMSP, MODIS, SAR etc.), linking observations to socio-economic and demographic information, bridging across and among different scales, and relating empirical measurements, spatial theory and modeling have been proven to a successful in an urban context. These potentials should be further elaborated on for global scale assessments. Basically, the framework exists to improve global urban observations. It is no up to earth observation community to respond to the challenges.

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