P3.1 ANALYSING DECADAL LAND-COVER CHANGE AS A POSSIBLE FLOOD-INDUCING EFFECT IN THE UPPER TISZA RIVER BASIN IN EASTERN EUROPE

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1. INTRODUCTION

After a few-decade-long dry period (20-30 years) in the last few years several serious flood events (Autumn, 1998; Spring, 1999, 2000, and 2001) occurred at the watershed of the Ukrainian and Hungarian parts of the river Tisza. The water level at many stations exceeded the previous historical record values during these recent floods. For instance, Fig. 1. presents the annual maximum water level (upper panel) at Vasarosnameny (at river Tisza, Hungary) between 1991 and 2001, as well, as the number of days above 1st order flood warning level in each year (lower panel). The positive decadal tendency in water level change is obvious, and the time series illustrate the considerable increase in frequency of very high water level (exceeding flood warning levels) after 1998.

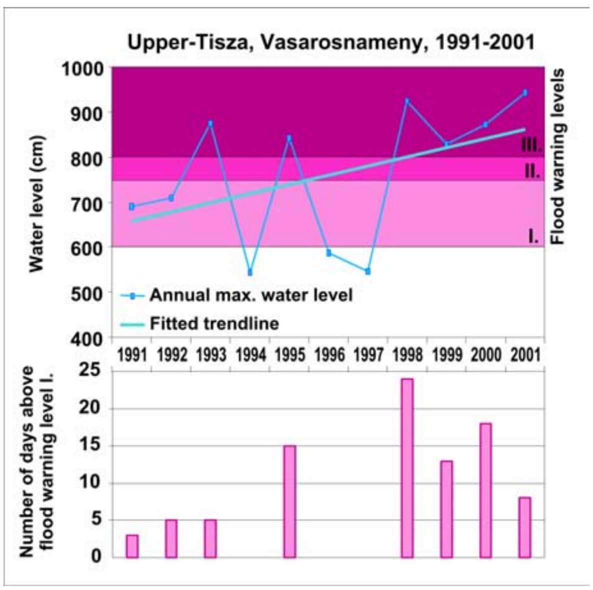

Fig. 1. Annual maximum water level and the number of days above 1st order flood warning at the river Tisza, Vasarosnameny, 1991-2001.

Because of the severe socio-economical consequences of recent floods, enhanced public interest appeared to analyze and clarify the complex relationships between flood events and their possible reasons. In order to fulfil this demand several aspects of recently increased flood frequency and intensity must be scientifically investigated. They include recent very intense clear cutting of forest at headwaters (on steep slopes of the Eastern Carpathian Mountains), increased frequency of storms with intense precipitation, change in annual precipitation distribution over subcatchments, longer and colder winter with considerable snow accumulation, regional effect of global warming, etc. In this paper one of the potential effects is analyzed, namely, the land-cover/land-use change of the upper part of the Tisza river basin. This area is shared by four countries (i.e., Romania, Ukraine, Slovakia, Hungary), the analysis presented here is accomplished on a subcatchment basis. For the separation of the watershed areas of tributary streams of the river Tisza the HYDRO1k Elevation Derivative Database (Verdin and Jenson, 1996) has been used. In case of a 28,000 km^2 large area it is obviously impossible to rely solely on ground-based measurements to estimate land-cover change. Therefore, remotely sensed satellite information must be considered, which guarantee appropriate spatial coverage for the seven selected subcatchments. In order to compare land-use/land-cover features between 1992-1993 and 2000-2001 the NOAA Global Land Cover Characteristics Data Base (Loveland et al., 2000) and the MODIS Land Cover Product (Friedl et al., 2002) have been applied.

The aim of the analysis presented here is to answer whether or not the forest area at the headwaters of the river Tisza noticeably decreased during the last decade. First, the datasets are presented followed by the description of the applied methodology. Then, the results and finally, the conclusions are provided in this paper.

2. DATA

Boundaries of the subcatchments are determined on the base of the HYDRO1k Elevation Derivative Database. Remotely sensed land cover information is compared using the NOAA Global Land Cover Characteristics Data Base (for 1992/1993) and the MODIS Land Cover Product (for 2000/2001).

2.1 *HYDRO1k Elevation Derivative Database*

HYDRO1k is a hydrological database (Verdin, 1997) with 1 km spatial resolution developed by the US Geological Survey's (USGS) Earth Resources Observation System Data Center from the USGS 30

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arc-second digital elevation model (GTOPO30) of the world (Verdin and Jenson, 1996). HYDRO1k contains 8 hydrological data sets for each continent, namely, hydrologically correct digital elevation model (DEM), derived flow directions, flow accumulations, slope, aspect, compound topographic (wetness) index, streamlines, and basins (Jenson and Domingue, 1988).

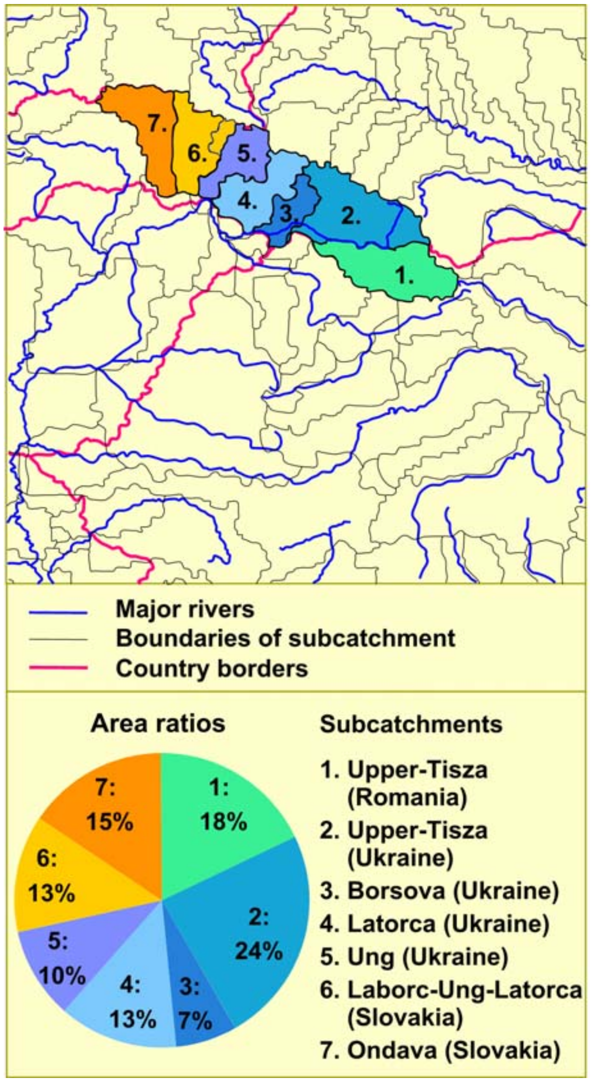

Fig. 2. Geographical location of the selected subcatchments of the Tisza river basin and their ratio compared to the total area of the watershed of the Upper-Tisza river outside of Hungary

In order to select the 7 subcatchments of the headwater of the river Tisza the basin data set (derived from streamlines and flow directions) has been used (Jenson, 1991). The geographical locations of the analyzed subcatchments are shown on Fig.2. One of the seven areas (No.1) is located in Romania, two of them (No.6 and 7) are in Slovakia, while the other four (No.2, 3, 4, 5) can be found in Ukraine. Furthermore, Fig.2. presents also the area-ratio of each subcatchment compared to the total area of the watershed of the Upper-Tisza river outside of Hungary. 18%, 54%, and 28% of the total area is located in Romania, in Ukraine, and in Slovakia, respectively.

2.2 *NOAA Eurasia Land Cover Characteristics Database*

The USGS EROS Data Center, the University of Nebraska-Lincoln, and the European Comission's Joint Research Centre have generated the Global Land Cover Characteristics (GLCC) Database (Muchoney et al., 1999). The 1 km spatial resolution GLCC database (Loveland et al., 2000) is separated by continents; in this analysis the Eurasian dataset is used. The entire data set is derived from 1 km Advanced Very High Resolution Radiometer (AVHRR) measurements of NOAA-satellites (Eidenshink and Faudeen, 1994; Ehrlich et al., 1994; Shimabukuro et al., 1997) from a one year period (April 1992 - March 1993). The original database includes several classification schemes (Townsend et al., 1991). The International Geosphere-Biosphere Programme (IGBP) Land Cover Classification (Belward et al., 1999) has been applied in our research. In order to summarize and visualize the main tendency of land-use/land-cover change during the last decade the 17 different land-cover categories have been clustered resulting in 7 simplified IGBP land-cover categories (Table 1).

Table 1. Land cover classes of the International Geosphere-Biosphere Program and the aggregated land cover classes used in forest-cover analysis

Original IGBP classes	Aggregated IGBP classes
Evergreen needleleaf forest Evergreen broadleaf forest Deciduous needleleaf forest Deciduous broadleaf forest Mixed forest Woody savannas	Forest
Closed shrublands Open shrublands Savannas Grasslands Permanent wetlands Barren and sparsely vegetated	Non-forest natural vegetation
Croplands	Croplands
Urban and built-up	Urban and built-up
Cropland/natural vegetation mosaic	Cropland/natural vegetation mosaic
Snow and ice Water bodies	Water, snow, ice
Unclassified	Unclassified

2.3 *MODIS Land Cover Product*

The MODIS Land Cover Product is a 1-km resolution dataset (Hodges et al., 2001; Friedl et al., 2002) developed by the NASA's Earth Observing System (EOS) Moderate Resolution Imaging Spectro-radiometer (MODIS) Land Science Team (Strahler et al., 1999). The data set is compiled from daily remotely sensed cloud-cleared, atmospherically-corrected surface reflectances using channels 1-7 data (Zhang et al., 1999). Among the different classification schemes provided by the MODIS Land Cover Product (Zhang et al., 2001) the aggregated IGBP Land Cover Classification is applied as well, as in the case of the NOAA dataset.

3. METHODOLOGY

First of all, it is necessary to synchronize the different geographical projections used in HYDRO1k and satellite datasets. The HYDRO1k and the NOAA Eurasia Land Cover Characteristics Database are available in Lambert azimuthal equal area projection and in Goodes homolosine projection, respectively (Steinwand et al., 1995). Both of them are provided on a continental basis, while the MODIS Land Cover Product uses the integerized sinusoidal grid projection with standard tiles representing 1200×1200 pixels on the earth (Dwyer, 2003.). In order to accomplish an appropriate geographical fitting 500×500-pixel-large area has been selected from each dataset containing the upper Tisza river basin. During the fitting process the projection of the MODIS dataset has been considered as the basis, and polynomial spatial warp transformation applied to the HYDRO1k and the NOAA datasets using easily identifiable special pixels (i.e., cities, lakes). After the geographical standardization the pixel representations of each land cover type is determined for the 7 selected subcatchments of the upper Tisza river basin in case of the 1992-1993 and 2000-2001 periods. And finally, either the area or the ratio of the different land cover types is compared.

4. RESULTS AND DISCUSSION

In order to answer whether or not land-use/land-cover change may play a key role in more severe and more frequent flood events through more intense and shorter run-off process, forest area is determined on the seven selected subcatchments of the Upper-Tisza river for the two periods: 1992-1993 and 2000-2001.

Fig. 3. focuses on the decadal change of the spatial extension of forests and non-forested areas at the watershed of the river Tisza. All the pixels (representing 1 km^2 area each) are classified into one of the following four categories, (1) forests becoming non-forested areas, (2) previously non-forest areas turning into forests, (3) forests remaining forests, and (4) non-forest areas remaining non-forested. The results suggest that forest area decreased considerably on three eastern/southeastern subcatchments by 900, 340, and 225 km^2 on the Romanian Upper-Tisza, the Ukrainian Upper-Tisza, and the Ukrainian Borsova subcachments, respectively. Taking into account the total subcachment areas these changes exhibit 18%, 5%, and 12%, respectively (Fig. 4.).

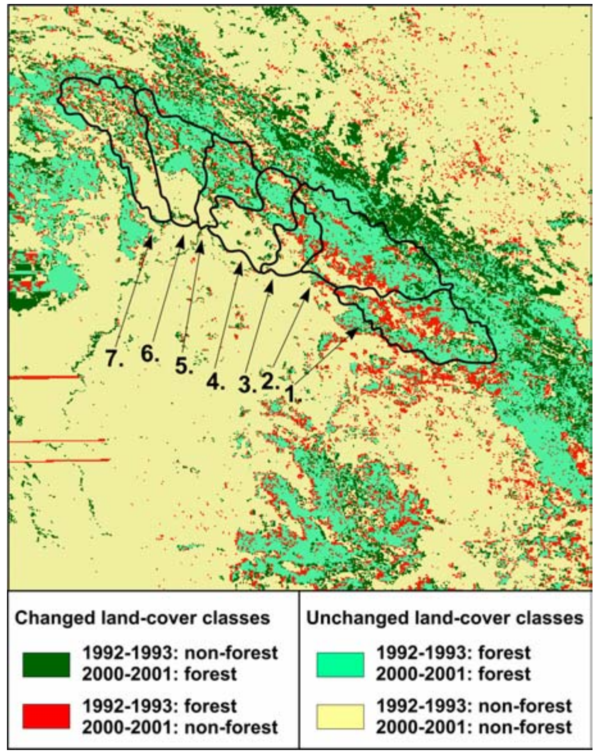

Fig. 3. Change in forest area on the Upper Tisza watershed between 1992/93 and 2000/01.
The total spatial coverage is 500 km × 500 km.
(the numbers of the subcatchments can be found in Fig. 2.)

On the other hand, the map of Fig. 3. illustrates that some deforestation can be detected in case of all the seven selected subcatchments. Nevertheless, the three western/northwestern subcatchments (i.e., the Ukrainian Latorca, the Ukrainian Ung, and the Slovakian Laborc-Ung-Latorca subcatchments) are slightly dominated by the increase of forest area (by 50 km^2, 60 km^2, and 210 km^2, respectively) between 1992/1993 and 2000/2001. Taking into account the total subcachment areas these slight increases of forest area exhibit about 1-6% (Fig. 4.). This positive tendency may be due to the increasing atmospheric concentration of CO_2 resulting in abundance of the vegetation. According to Bartholy et al. (2001) mostly positive tendency of the Normalized Difference Vegetation Index (NDVI) is detected in Central Europe (especially in mountains) during the last two decades implying more intense photosynthesis and forest/vegetation growth. For instance, considerable increase of forest area occurred at the northeastern part of the Carpathian

Mountains as Fig. 3. shows but this region does not belong to the watershed of the river Tisza.

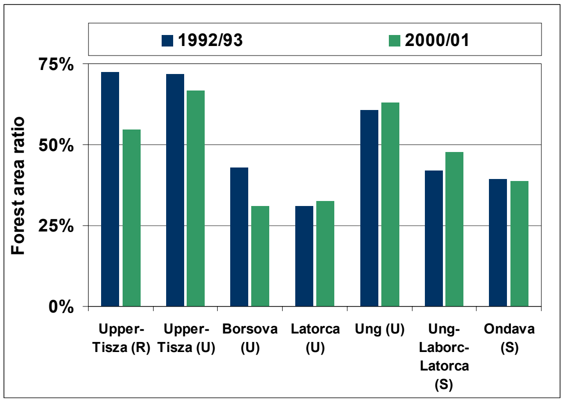

Fig. 4. Decadal change in forest area at the seven selected subcatchments of the Upper-Tisza watershed.

Finally, on the most western subcatchment (belonging to the river Ondava in Slovakia) a slight decrease of forest area by about 20 km^2 can be detected, which is not significant. Taking into account the total subcachment area this means less than 1% (Fig. 4.).

Comparing the spatial distribution of forest-increased and forest-decreased pixels in the seven selected subcatchments of the Upper-Tisza region, deforested pixels form quite large, coherent spatial structures, while forested pixels are sparse, less coherent, they form only small patches within the subcatchments.

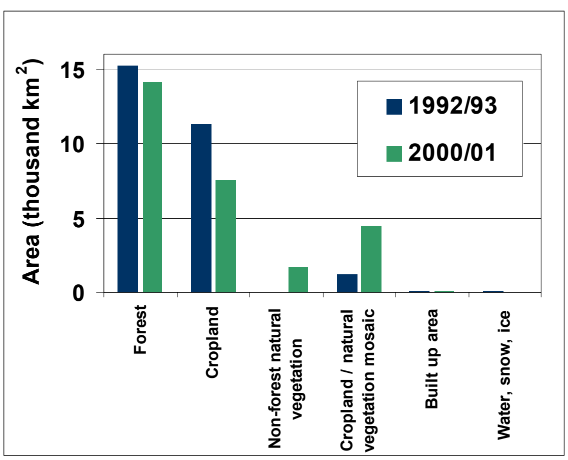

Fig. 5. Total land cover change of the Upper-Tisza watershed during the last decade

Besides the forest area other land-use/land-cover classes changed considerably, as well. Fig. 5. summarizes the change in different land-use/land-cover classes on the entire investigated area (28,000 km^2) between 1992-1993 and 2000-2001. The overall tendencies represent the decrease of forests and croplands (by 1,200 km^2 and 3,800 km^2, respectively), and the increase of non-forest natural vegetation and cropland/natural vegetation mosaic (by 1,700 km^2 and 3,300 km^2, respectively) in the last decade. Built-up area and water/snow/ice surfaces did not change significantly during this short period.

Based on the satellite information croplands decreased by about 10-20% in all selected subcatchments during the last decade. This may be the consequence of the agricultural crisis in the Eastern European region after the political changes of the early 1990s. In these countries large portion of the agricultural areas remain uncultivated because of the reprivatization process and the chaotic changes of land-owners. Furthermore, the characteristical size of agricultural fields decreased due to the reprivatisation, and most of the present owners are not able to crop their fields due to the lack of financial sources and appropriate farming technique.

Fig. 5. illustrates also the increasing ratio of the non-forest natural vegetation and cropland/natural vegetation mosaic in all subcatchments. In the change of the spatial extent of these land-cover classes mostly weak quality vegetation (e.g., ragweed) is the main component. On the other hand, built-up area did not change significantly during the last decade since urbanization does not dominate this region. In case of water surfaces decadal time scale is too small for any significant change. Furthermore, the entire Carpathian Mountains are below 2,700 m, therefore, permanent snow/ice is not present and the change of snow/ice extent can be eliminated.

5. CONCLUSIONS

Recently, several severe flood events occurred in the Carpathian Basin. Most of them cannot be explained solely by heavy precipitation episodes. In this paper one of the possible reasons has been investigated, namely, whether or not land-use/land-cover changes in the Eastern Carpathians may affect the more intense flood events on the Great Hungarian Plains. The presented study of the headwater region of the river Tisza is based on the analysis of land-cover changes in the seven subcatchments (Upper-Tisza in Romania; Upper-Tisza, Borsova, Latorca, and Ung in Ukraine; Laborc-Ung-Latorca and Ondava in Slovakia). In order to detect the land-use/land-cover changes remotely sensed fine resolution (1 km) datasets for 1992-1993 and 2000-2001 (NOAA and MODIS land cover products, respectively) are compared.

Based on the results the following conclusions can be drawn.

1. Forest area decreased by 3-4% on average in the watershed of the Upper-Tisza river outside of Hungary, which equals to 1,200 km^2 area out of the entire 28,000 km^2 large area.

2. In the eastern/southeastern subcatchments forest area decreased during the last decade by about 10% of the total area, specifically, by 18% (900 km^2), 5% (340 km^2), and 12% (225 km^2) at the Upper-Tisza

in Romania, at the Upper-Tisza in Ukraine, and at the Borsova subcatchment in Ukraine, respectively.

3. Slight increase of forest area is detected in the western/northwestern subcatchments resulting in about 300 km^2 larger forests.

4. Besides forest area other land-cover classes changed as well. Specifically, spatial extension of croplands decreased considerably (by 3,800 km^2), while area of non-forest natural vegetation and cropland/natural vegetation mosaic increased by 1,700 km^2 and 3,300 km^2, respectively. Built-up area and water/snow/ice surfaces did not change significantly during the last decade.

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REFERENCES

Bartholy, J., Pongracz, R., Barcza, Z., 2001: Analysis of vegetation index values and their variations in the Atlantic-European region and the Carpathian Basin based on satellite observations. *Proceedings of the 5th European Conf. on Applications of Meteorology ECAM 2001 and 1st Ann. Meeting of European Meteorol. Society*. CD-ROM. Budapest, Hungary.

Belward, A.S., Estes, J.E., Kline, K.D., 1999: The IGBP-DIS 1-Km Land-Cover Data Set DISCover: A Project Overview. *Photogram. Eng. Remote Sens.,* **65**, 1013-1020.

Dwyer, J., 2003: MODIS reprojection tool user's manual, release 3.1. Dept. of Mathematics and Computer Science, South Dakota School of Mines and Technology, USGS EROS Data Center, Sioux Falls, South Dakota. 57p.

Ehrlich, D., Estes, J.E., Singh, A., 1994: Application of NOAA-AVHRR 1 km data for environment monitoring. *Int. J. Remote Sensing,* **15**, 145-161.

Eidenshink, J.C., Faudeen, J.L., 1994: The 1 km AVHRR global land data set: First stages in implementation. *Int. J. Remote Sensing,* **15**, 3443-3462.

Friedl, M.A., McIver, D.K., Hodges, J.C.F., Zhang, X., Muchoney, D., Strahler, A.H., Woodcock, C.E., Gopal, S., Schnieder, A., Cooper, A., Baccini, A., Gao, F., Schaaf, C., 2002: Global land cover from MODIS: Algorithms and early results. *Remote Sens. Environ.,* **83**, 287-302.

Hodges, J.C.F., Friedl, M.A., Strahler, A.H., 2001: The MODIS global land cover product: new data sets for global land surface parameterization. *Proceedings of the Global Change Open Science Conference*. Amsterdam, the Netherlands.

Jenson, S.K., 1991: Applications of hydrologic information automatically extracted from digital elevation models. *Hydrological Processes,* **5**, 31-44.

Jenson, S.K., Domingue, J.O., 1988: Extracting topographic structure from digital elevation data for Geographic Information Systems analysis. *Photogram. Eng. Remote Sens.,* **54**, 1593-1600.

Loveland, T.R., Reed, B.C., Brown, J.F., Ohlen, D.O., Zhu, J, Yang, L., Merchant, J.W., 2000: Development of a global land cover characteristics database and IGBP DISCover from 1-km AVHRR data. *Int. J. Remote Sensing,* **21**, 1303-1330.

Muchoney, D., Strahler, A., Hodges, J., LoCastro, J., 1999: The IGBP DISCover confidence sites and the system for terrestrial ecosystem parameterization: tools for validating global land cover data. *Photogram. Eng. Remote Sens.,* **65**, 1061-1067.

Shimabukuro, Y.E., Carvalho, V.C., Rudorff, B.F.T., 1997: NOAA-AVHRR data processing for the mapping of vegetation cover. *Int. J. Remote Sensing,* **18**, 671-677.

Steinwand, D.R., Hutchinson, J.A., Snyder, J.P., 1995: Map projections for global and continental data sets and an analysis of pixel distortion caused by reprojection: *Photogram. Eng. Remote Sens.,* **61**, 1487-1497.

Strahler, A., Muchoney, D., Borak, J., Friedl, M., Gopal, S., Lambin, E., Moody, A., 1999: MODIS land cover product algorithm theoretical basis document, version 5.0. Center for Remote Sensing, Boston University, Boston, Massachusetts, 72p.

Townsend, J., Justice, C., Li, W., Gurney, C., McManus, J., 1991: Global land cover classification by remote sensing: present capabilities and future possibilities. *Remote Sens. Environ.,* **35**, 243-255.

Verdin, K.L., 1997: A System for Topologically Coding Global Drainage Basins and Stream Networks. *Proceedings of the 17th Annual ESRI Users Conference*. CD-ROM. San Diego, California.

Verdin, K.L., Jenson, S.K., 1996: Development of continental scale digital elevation models and extraction of hydrographic features. *Proceedings of the Third Int. Conf./Workshop on Integrating GIS and Environmental Modeling*. CD-ROM. Santa Fe, New Mexico.

Zhang, X., Hodges, J.C.F., Schaaf, C., Friedl, M.A., Strahler, A.H., Gao, F., 2001: Global vegetation phenology from AVHRR and MODIS data. *Proceedings of the 2001 IEEE Int. Geosciences and Remote Sensing Symp*. Sydney, Australia.

Zhang, X., DeFries, R., Hansen, M., Townshend, J., DiMiceli, C., Sohlberg, R., Huang, C., 1999: MODIS enhanced land cover and land cover change product algorithm theoretical basis documents, version 2.0. Univ. of Maryland, College Park, Maryland, 93p.