AN EARTH OBSERVATION-SUPPORTED STRATEGY LINKING BIOPHYSICS AND SOCIO-ECONOMICS FOR ADDRESSING WATER VULNERABILITY

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Objectives

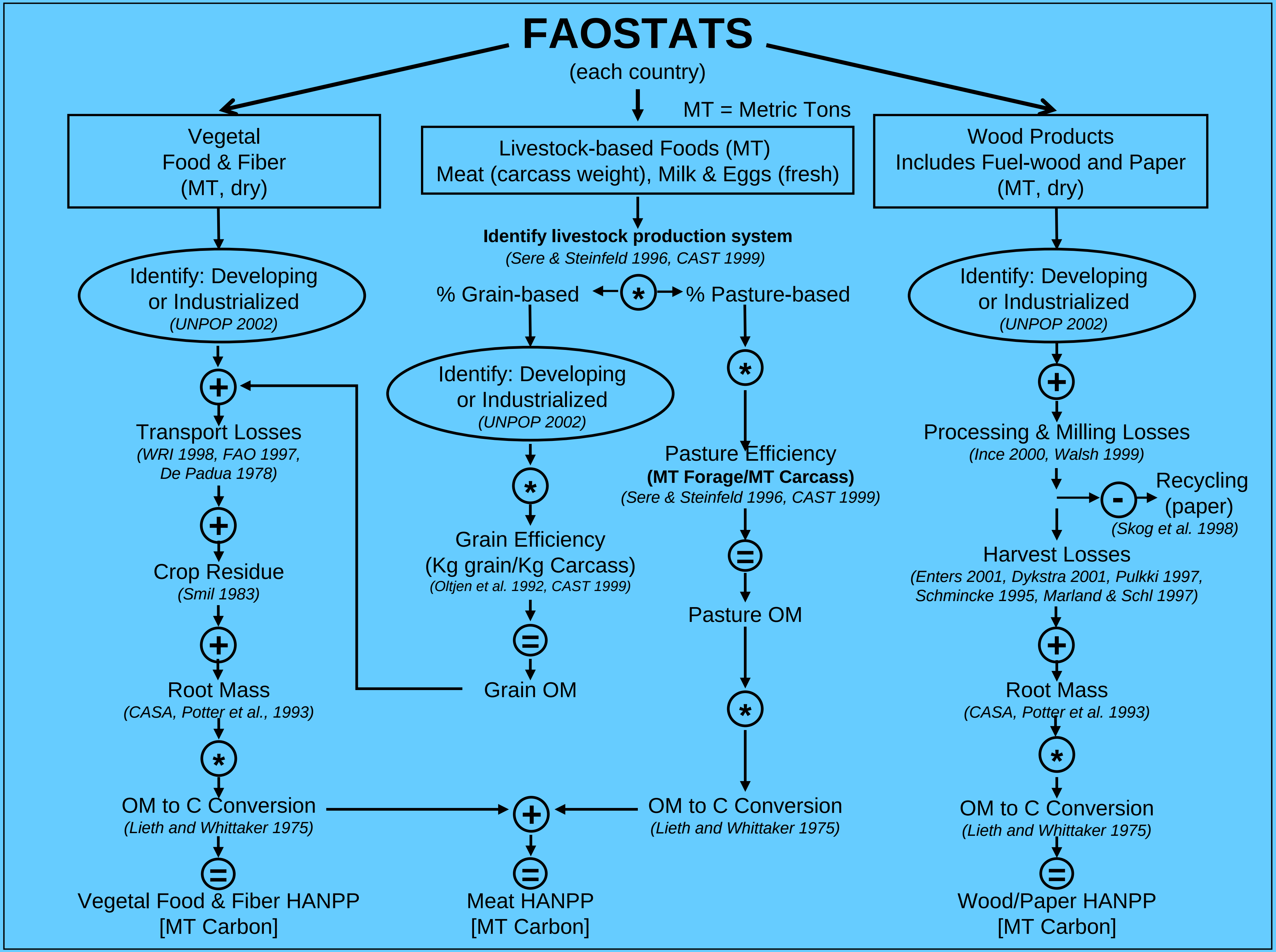
- We are developing an EO-supported biophysical modeling approach for quantifying water requirements based on climate conditions and crop type.
- The results will be used as input to agro-ecological models to explore the interactions of socio-economic land use/land cover change and climate.
- The work is a collaborative effort between NASA's Goddard Space Flight Center, the Institute for the Study of Society and Environment at the National Center for Atmospheric Research, and IFPRI.

Human Demand for Products of Photosynthesis

• How do we compare the rates of NPP-Carbon supply and demand globally, regionally, and locally?
How do they (rates) vary with respect to socio-economics and climate?

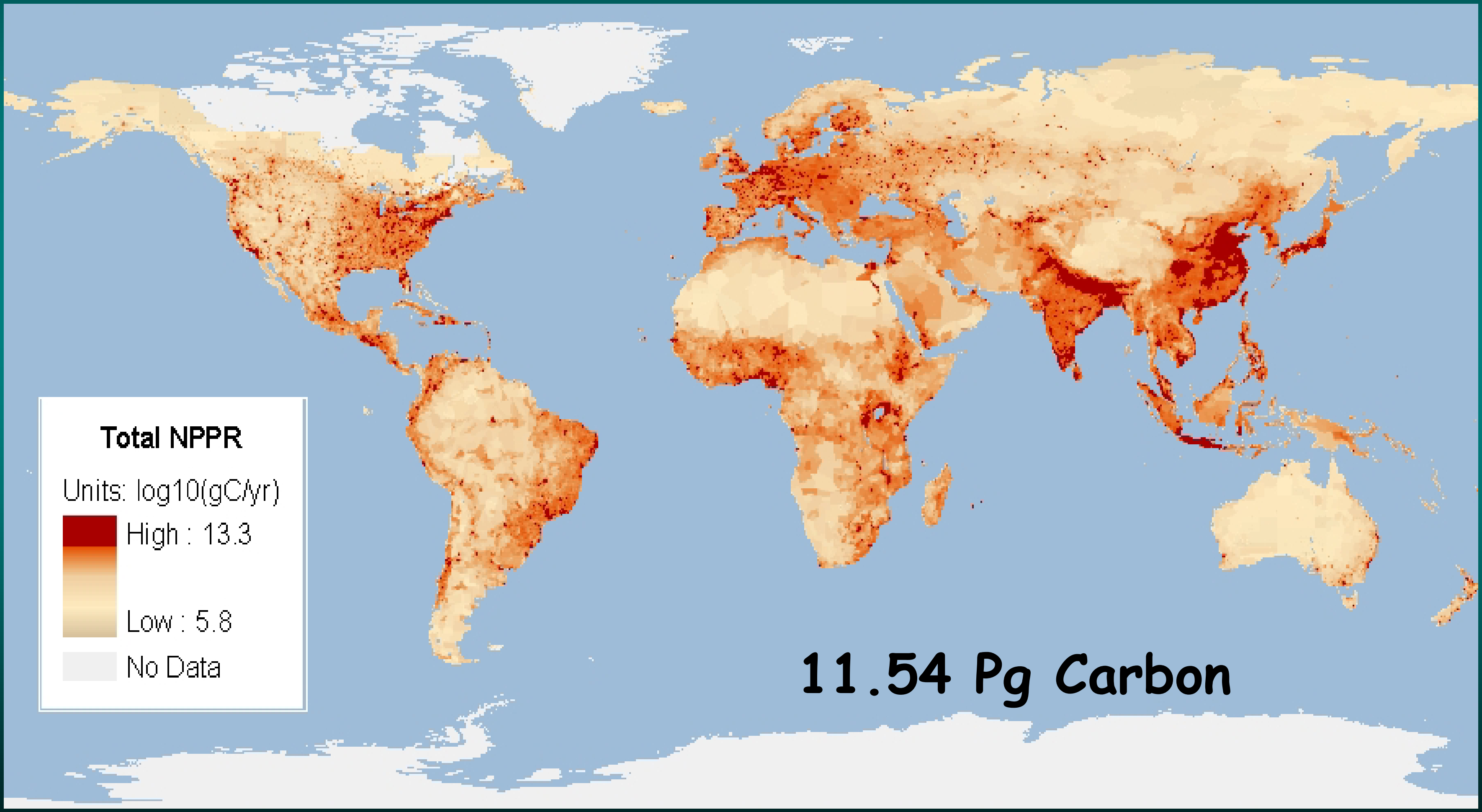
• Can we use satellite supported methods for scenario building and eventual prediction?

M. L. Imhoff et al. , NATURE, vol. 429, 24 June, 2004

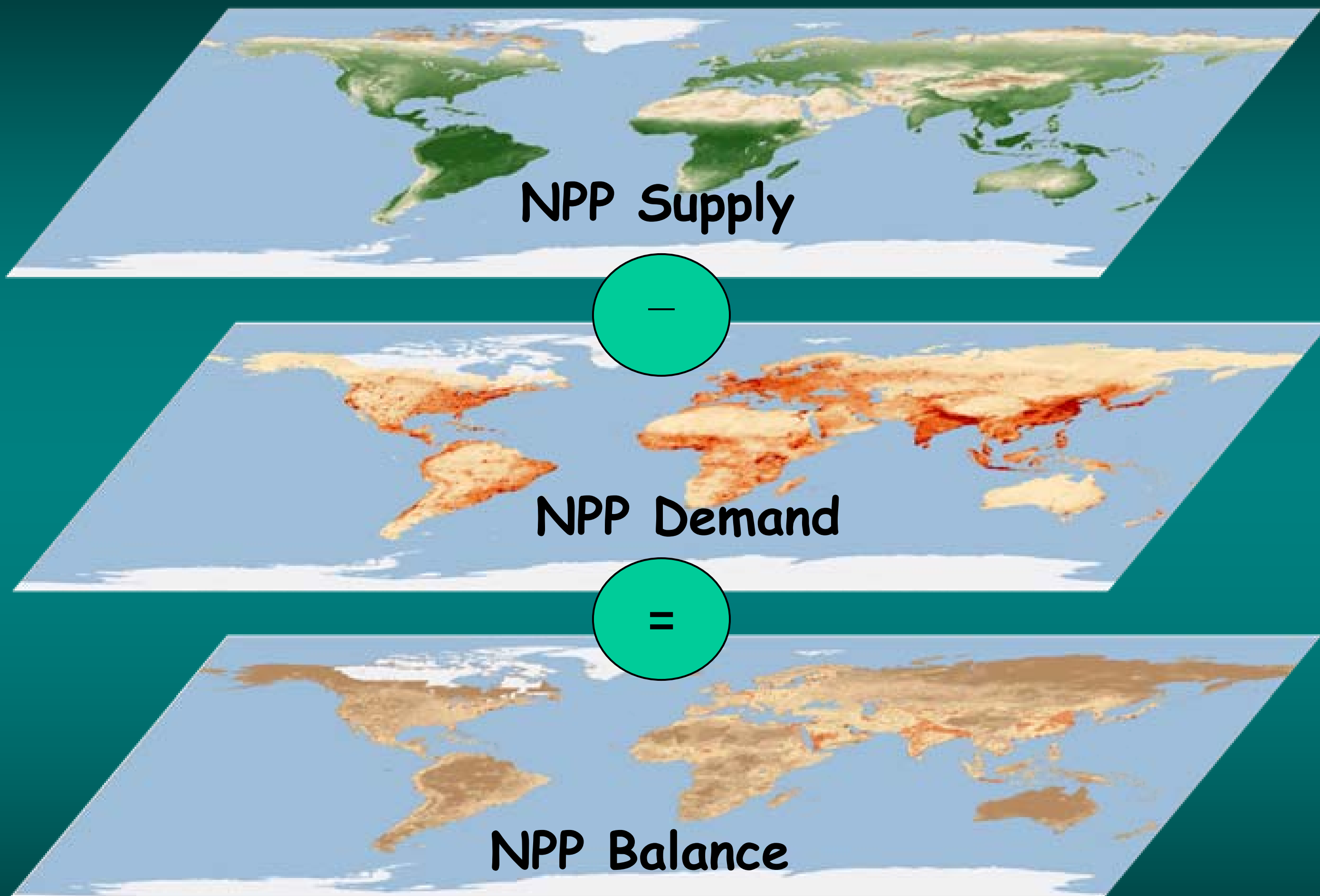

FAOSTATS
(each country)
MT = Metric Tons
Vegetal
Food & Fiber
(MT, dry)
Livestock-based Foods (MT)
Meat (carcass weight), Milk & Eggs (fresh)
Wood Products
Includes Fuel-wood and Paper
(MT, dry)
Identify: Developing
or Industrialized
(UNPOP 2002)
Identify livestock production system
(Sere & Steinfeld 1996, CAST 1999)
% Grain-based
*
% Pasture-based
Identify: Developing
or Industrialized
(UNPOP 2002)
+
Transport Losses
(WRI 1998, FAO 1997,
De Padua 1978)
+
Crop Residue
(Smil 1983)
+
Root Mass
(CASA, Potter et al., 1993)
*
OM to C Conversion
(Lieth and Whittaker 1975)
=
Vegetal Food & Fiber HANPP
[MT Carbon]
Identify: Developing
or Industrialized
(UNPOP 2002)
*
Grain Efficiency
(Kg grain/Kg Carcass)
(Oltjen et al. 1992, CAST 1999)
=
Grain OM
*
Pasture Efficiency
(MT Forage/MT Carcass)
(Sere & Steinfeld 1996, CAST 1999)
=
Pasture OM
*
OM to C Conversion
(Lieth and Whittaker 1975)
+
=
Meat HANPP
[MT Carbon]
+
Processing & Milling Losses
(Ince 2000, Walsh 1999)
-
Recycling
(paper)
(Skog et al. 1998)
Harvest Losses
(Enters 2001, Dykstra 2001, Pulkki 1997,
Schmincke 1995, Marland & Schl 1997)
+
Root Mass
(CASA, Potter et al. 1993)
*
OM to C Conversion
(Lieth and Whittaker 1975)
=
Wood/Paper HANPP
[MT Carbon]

Annual Human NPP Carbon Demand

Terrestrial NPP Required for Food and Fiber (1995)

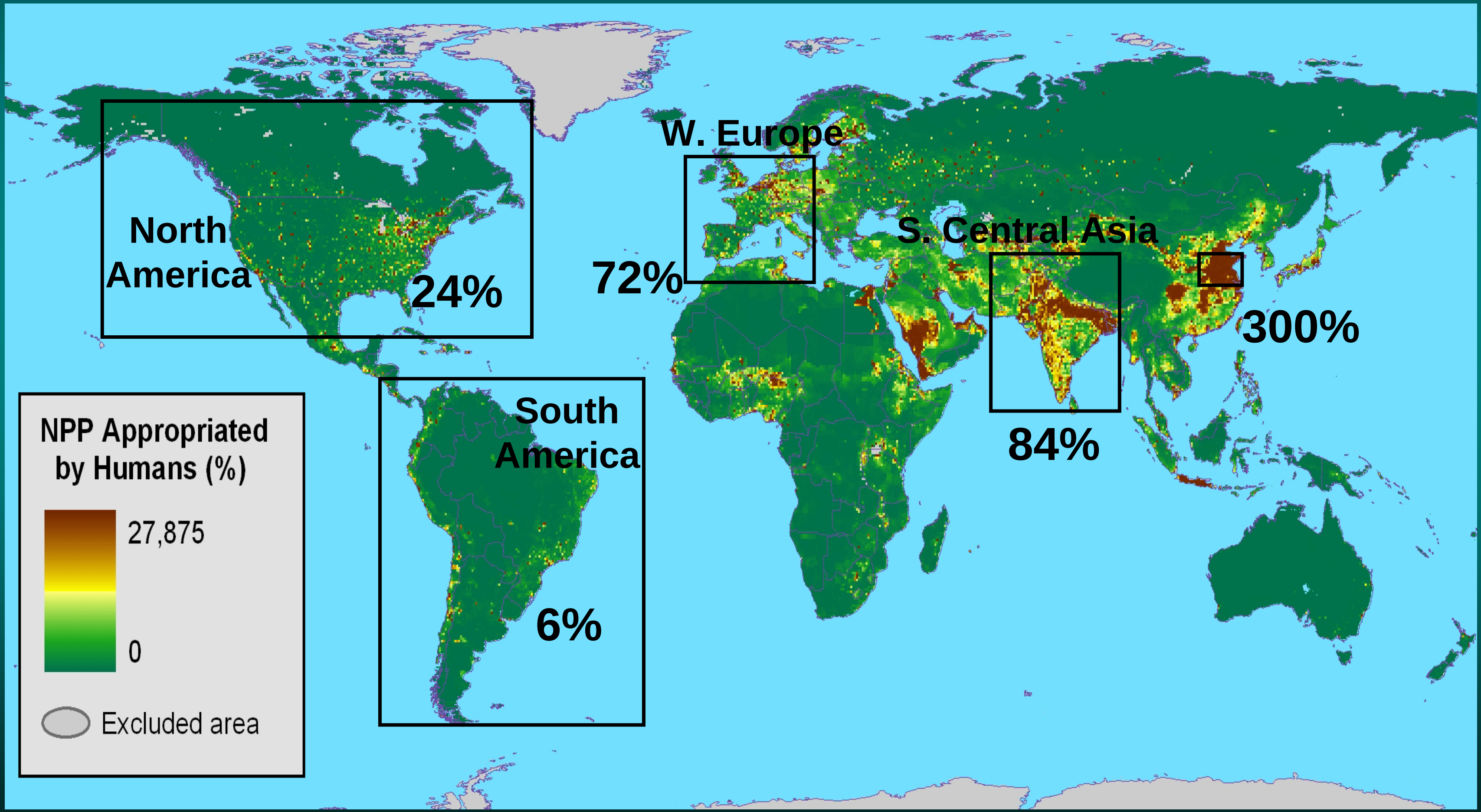


NPP Carbon Balance



NPP Demand as % of Supply

Global NPP Demand is 20% of Supply (land)
There are large regional and local variations



[Locating Risks to Biodiversity: A Carbon Balance Approach CARBON-0000-0009] M. L. Imhoff, PI

How HANPP Changes as a Function of: Population, Affluence, and Technology

I = PAT

- The ecological impact [I] of human activities involves population size [P], consumption levels [A, for "affluence"], and the technologies employed [T] (Holdren and Ehrlich, 1976).

Scenario	P*	A**	T***	HANPP (PgC)
1	↑	–	–	17.42
2	–	↑	–	20.19
3	–	↑	↑	16.26
4	↑	↑	–	31.59
5	↑	↑	↑	25.5

↑(increase), – (no change from the baseline 1995 intermediate estimate).

*** Population increase from 5.69 Billion (global population in 1995) to 8.92 Billion (estimated global population in 2050; Ref 18).**

**** Affluence increase applies average *per capita* consumption of industrialized countries (in 1995) for all countries.**

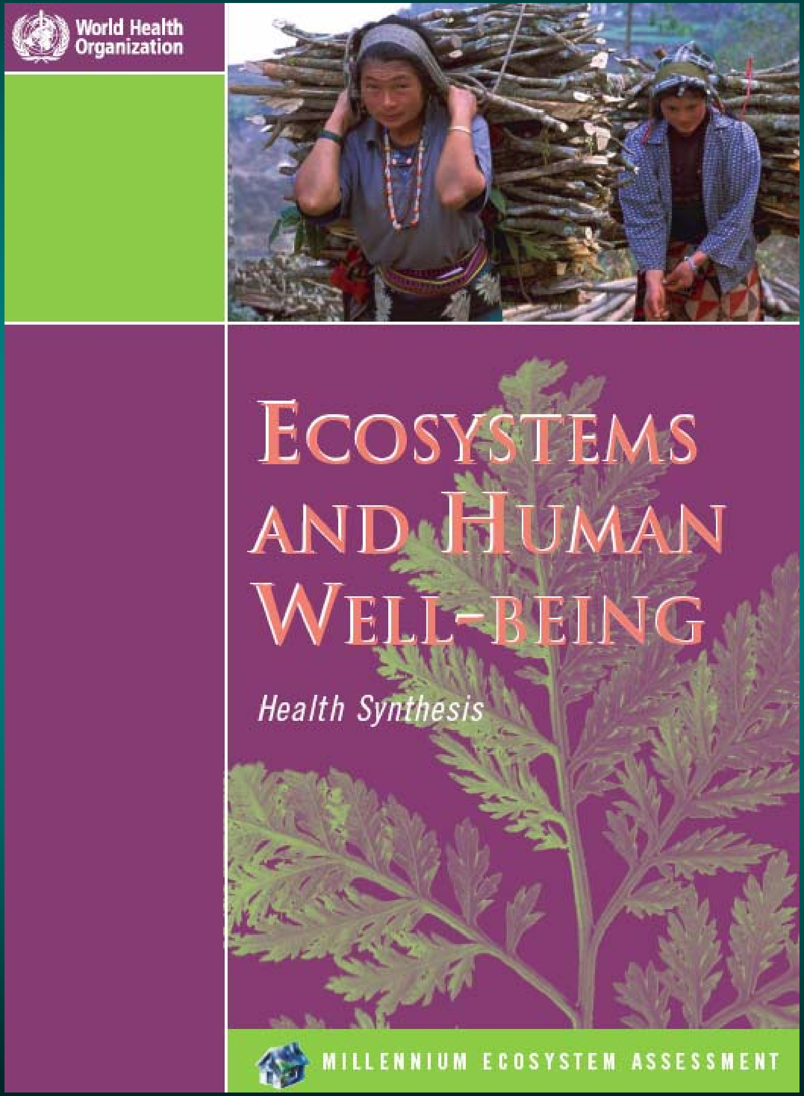
***** Technology increase applies technological efficiencies of industrialized countries (in 1995) to all countries.**

† *Per capita* fuel wood use in developing countries reduced to average for industrialized countries in 1995.

Carbon and Water Cycles are Tightly Connected within this domain

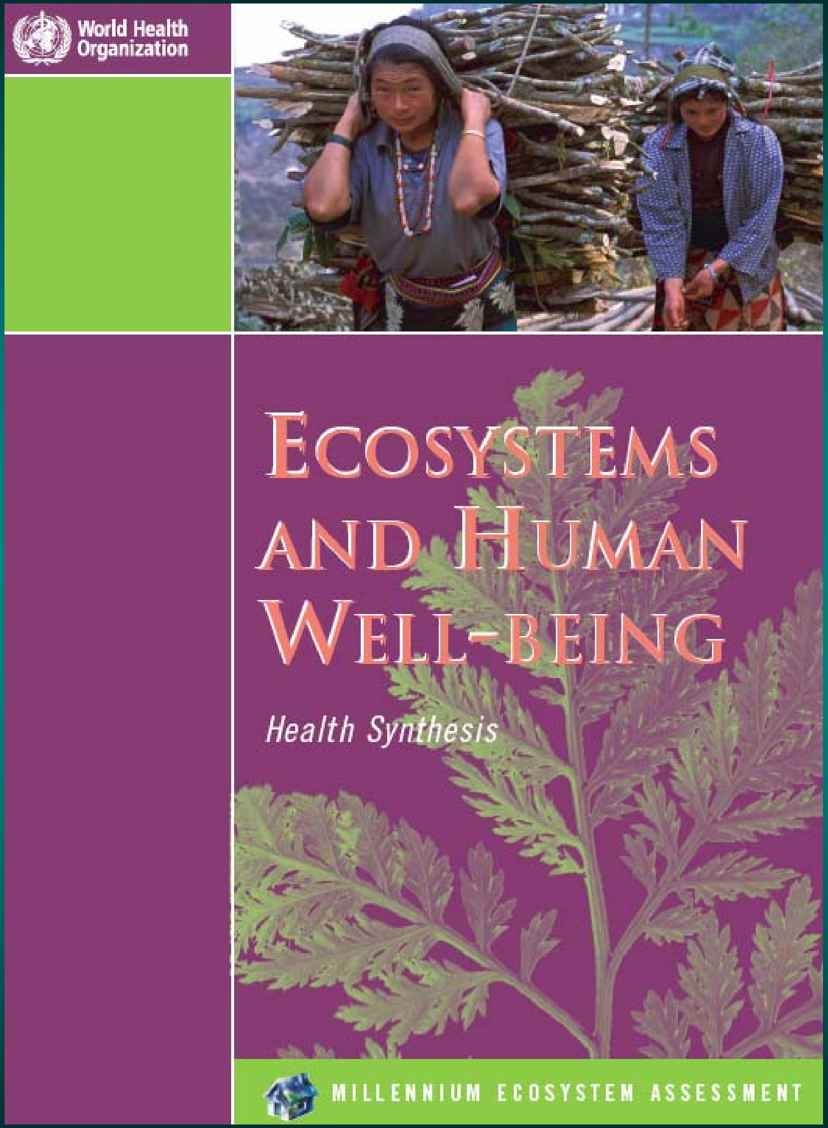
- Human demand for products of photosynthesis strongly influences the water cycle through land transformation and the diversion and extraction of fresh water needed to support agriculture.
- More than 70% of the planet's available fresh water supply is used for irrigation
  - 22% industrial and 8% for domestic use.
- Competition for fresh water is the subject of conflicts around the world where political boundaries dissect natural watersheds and aquifers.
- By 2025 nearly 66% of the world population will live in water stressed conditions (UNEP).

MILLENNIUM ECOSYSTEM ASSESSMENT



In the 200 years for which we have reliable data, overall growth of consumption has outpaced increased efficiencies in production processes.

Economic growth tends to increase consumption and the projected growth in the next 45 years is 200 - 400%.



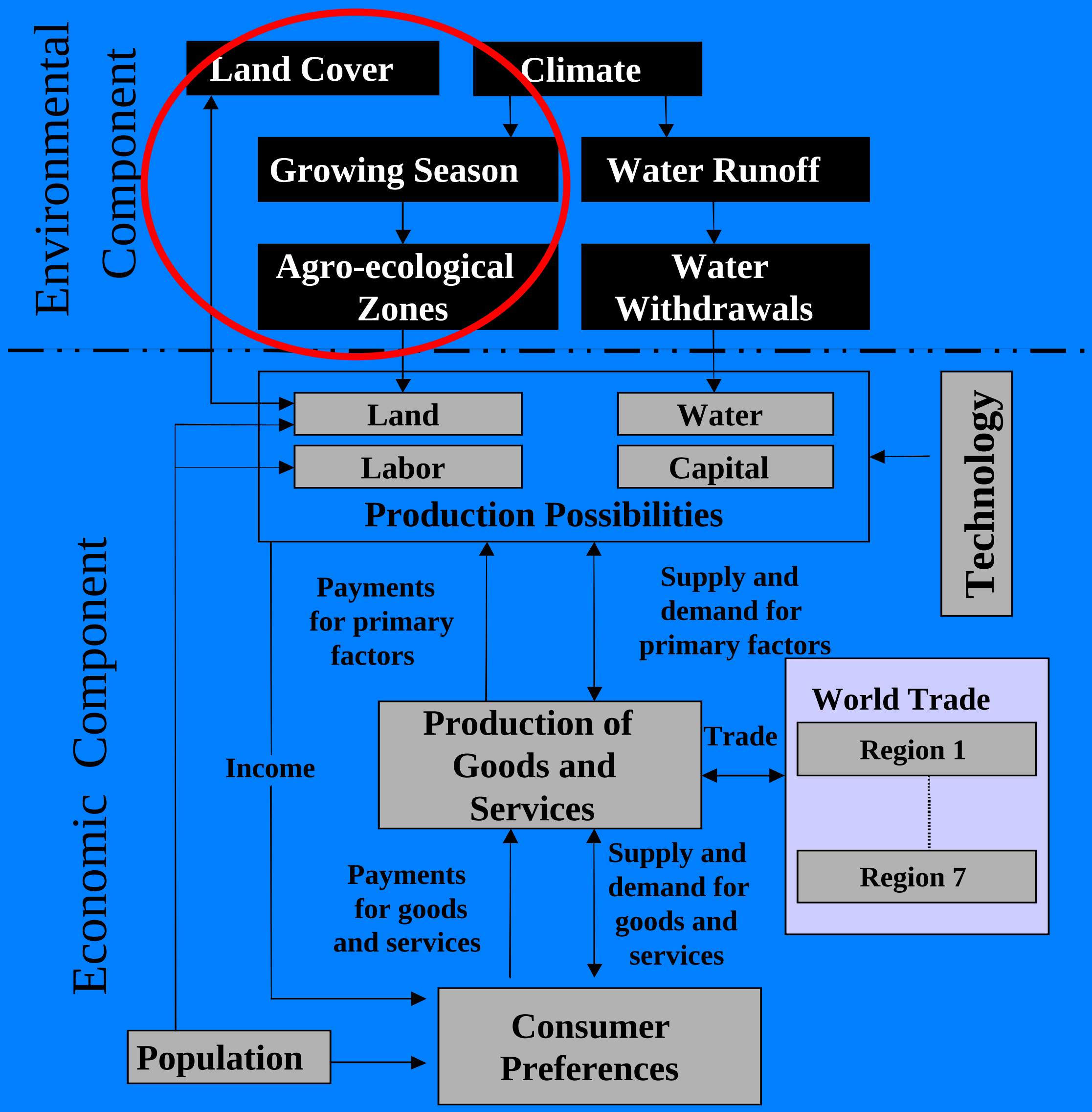
Demand for food is projected to grow by 70-80% and water by 30-85%.

Food security is not achieved under any of the MA scenarios by 2050.

The Socio-economics of Climate

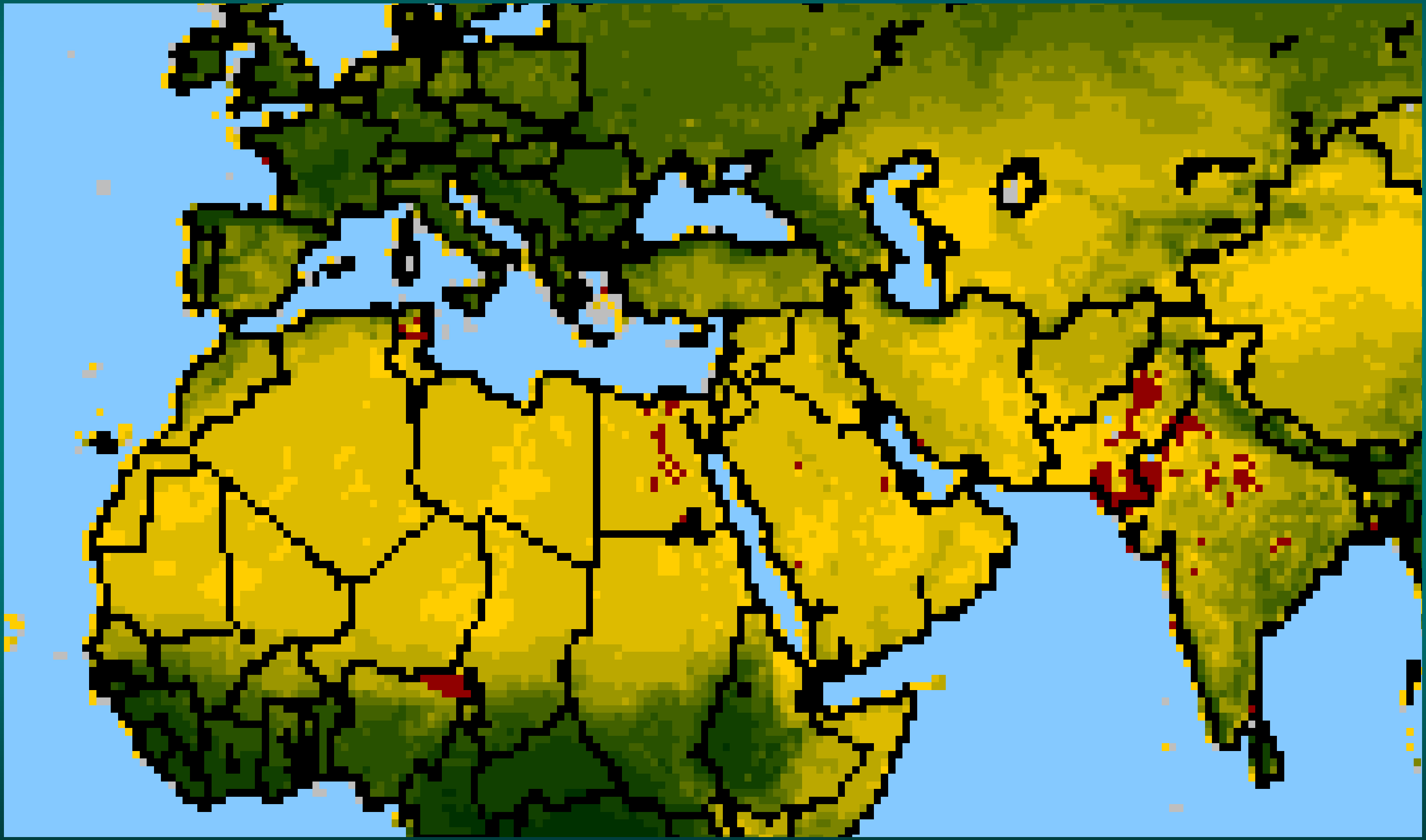
- For …semi-arid lands of central and northern Eurasia, socio-economic shifts are likely to eclipse changes in mean climate as a driver of the future relation between water supply and demand (Vorosmarty et al., 2000).
- It is critical that we begin to understand the environmental and socio-economic consequences of **short-term variations** in regional climate where the balance between supply and demand is fragile.
- Agro-economic models require accurate and current information on irrigated land and growing season.

General Equilibrium Economic Model Framework



Areas Where NPP balance is Negative

visible at 1deg grid resolution



Could be harvest reporting error or NPP miscalculation in large irrigated areas.

Hypotheses

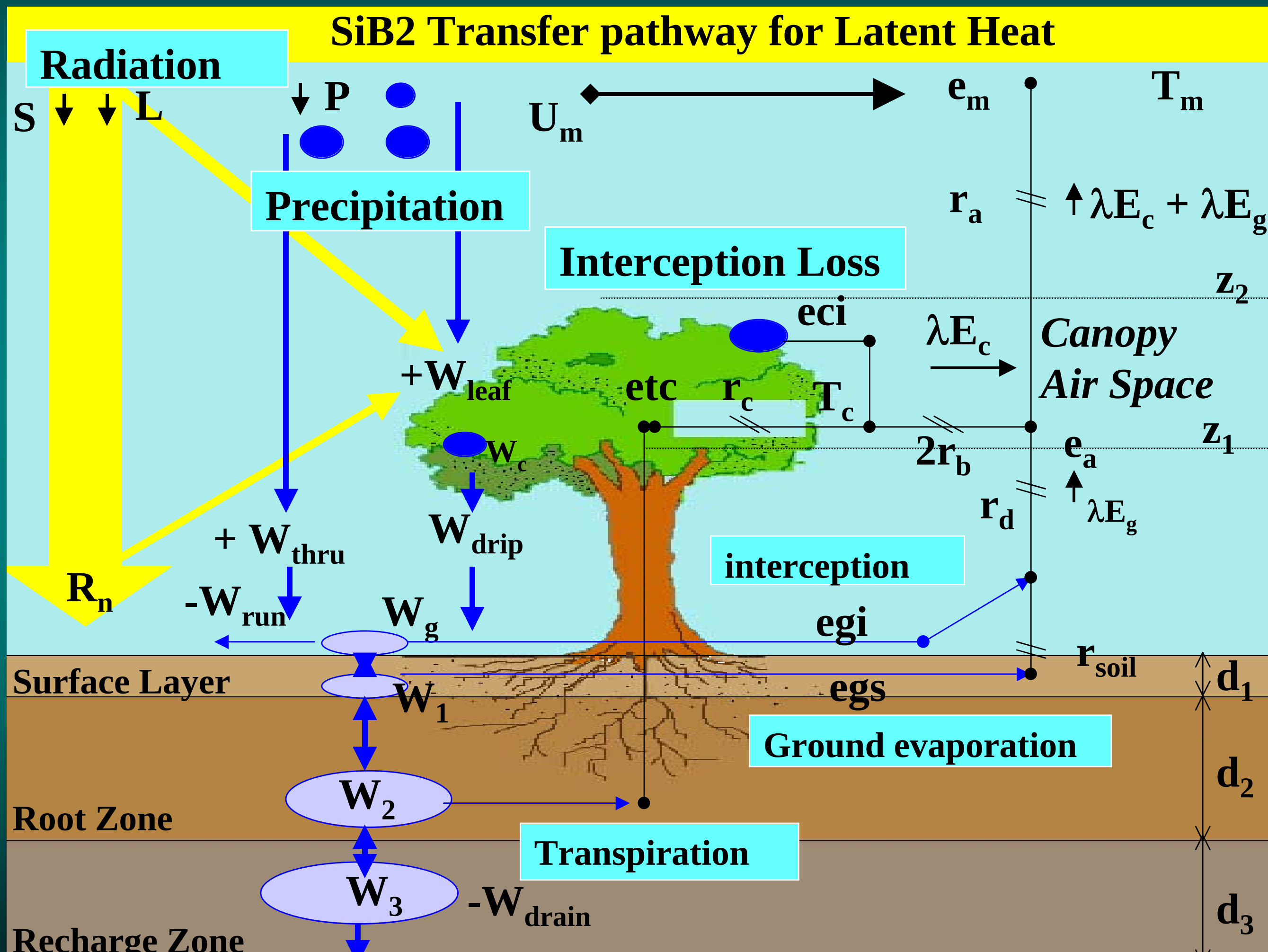
- Using MODIS vegetation indices, irrigated lands can be defined by LAI's that exceed what can be supported by the prevailing climatology.
- Using biophysical models, the minimum amount of irrigation water can be estimated by simulating the quantity required beyond precipitation to stay above PWP for observed LA.
- We postulate that the water flux difference is proportional to environmental risk and can be used as an indicator over time.

Methods

- Inverse process approach using MODIS LAI, climate, and biophysical modeling (SiB) to quantitatively estimate the minimum water requirements for agriculture in semi-arid and arid regions.
- Irrigated areas are out of equilibrium with local climate, i.,e., they support LA's that are greater than can be supported by local precipitation.
- We will use the model to estimate the amount of water required *over local precipitation* to account for ET given temperature, soil texture, crop type, and observed leaf area.
- Minimum water requirement will be estimated using the PWP for the crop type.

Simple Biosphere Model (SiB2)

pathway for the latent heat flux calculation



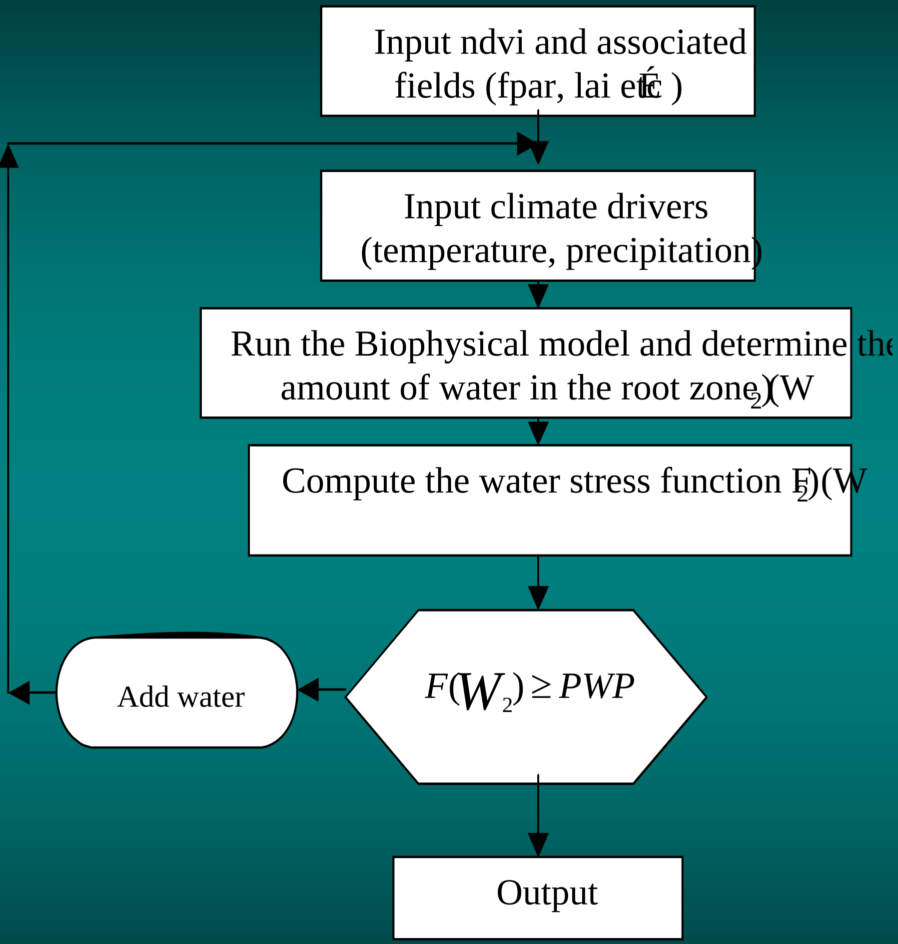
Iterative Inverse SiB2 process

Baseline:
-observed MODIS (NDVI/EVI) (updated every16 days) and local meteorology (obtained hourly from daily observations), which includes precipitation.

Water is added to keep the water stress function greater (less negative water potential) than the permanent wilting point (PWP).

Output is the amount of water required to maintain that balance.

Irrigation water is estimated by subtracting the canopy and ground intercept terms leaving only water infiltrating the soil surface (MINIMUM REQUIREMENT).



TEST SITES

- We will evaluate the cross-scale regional robustness of this approach using two test areas:
  - 1) the U.S. Mexico border, and
  - 2) the Aral Sea basin in Central Asia (within the NEESPI boundaries).
- In both areas the intersection of rapid agricultural/economic development and water availability has had an unprecedented impact on the both the physical and socio-political environments.

The Karakum Canal in Turkmenistan

- The Karakum Canal is the longest manmade canal in the world.
- The canal diverts water from the Amudarya River and Aral Sea Basin and diverts it into the Caspian Basin for human settlements and the production of wheat and cotton.
- Exactly how much water is diverted is unknown.
  - Estimates run from 10 to 20 cubic km from a high discharge of 70 cubic km in the Amudarya River in good water years.


Kazakhstan
Caspian Sea
(Baku)
Baky
Uzbekistan
(Tashkent)
Toshkent
Bishkek
Kyrgyzstan
Tajikistan
Dushanbe
Turkmenistan
Ashgabat
Tehran
Mashhad
(Kabul)
Kabol
Rawalpindi
Afghanistan
Esfahan
© 2006 Europa Technologies
Image © 2006 NASA
© 2006 National Geographic Society
Image © 2006 TerraMetrics
Pointer 40° 53'00.26"N 61° 30'53.87"E elev 378 ft
Streaming |||||||||| 100%
Eye alt 1246.00 mi

Karakum Canal

Ashgabat & Kerki Test Areas

Ashgabat - Annau Test Site

2003 wet year,
2004 average,
2006 - droughty

Test site: 37.92 N and 58.57 E
Near Annau - 15 minutes from Ashkhabad.

U.S. Mexico Border
Rio Conchos - Lower Rio Grande

- Prolonged drought and bi-national legal framework impact water management and negotiations.
- Assessment of relationships between land use change, water utilization, and climate variability and change is needed.

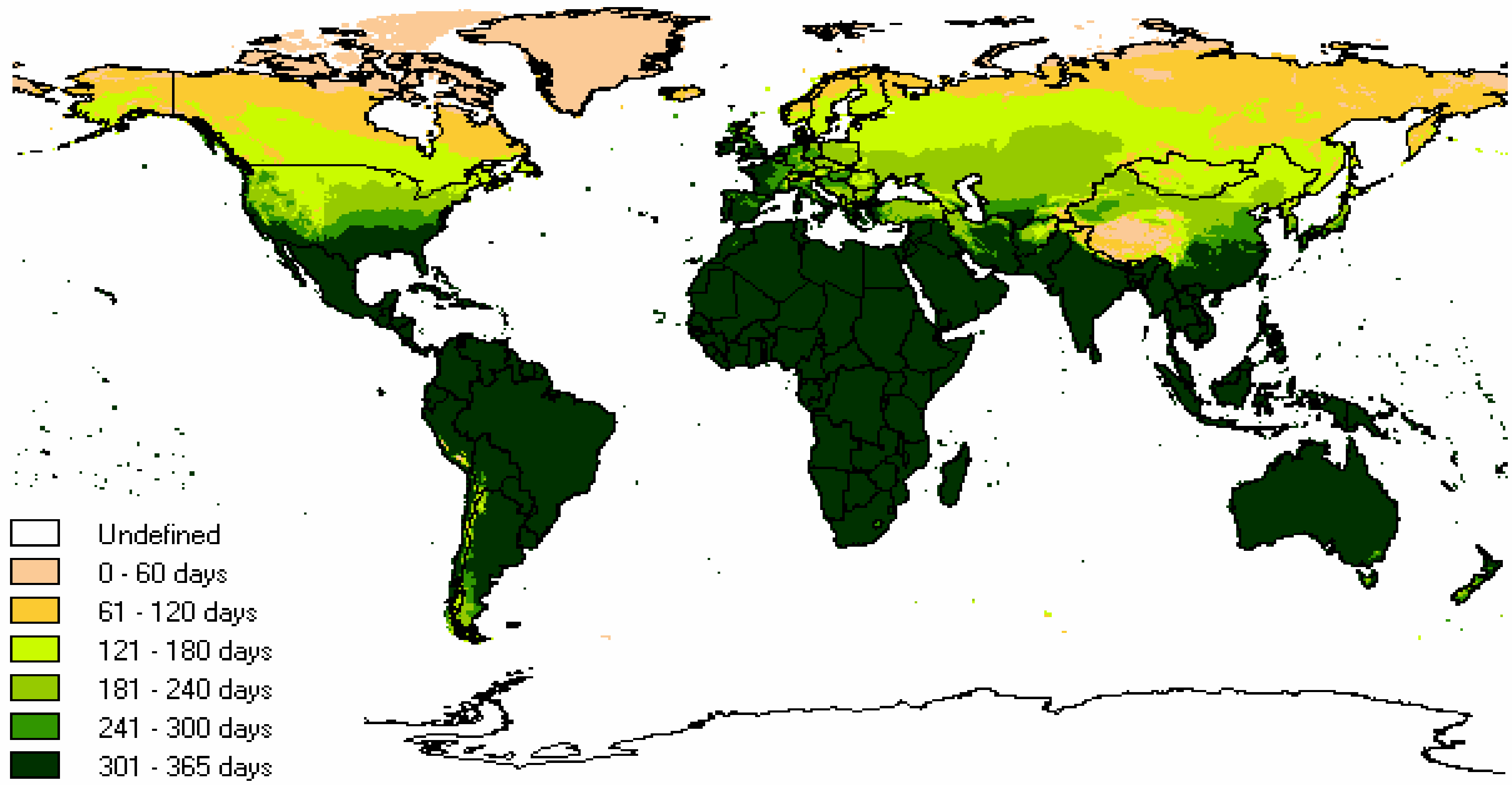

Harlingen
Cameron
Brownsville

Progress Timeline

- Year 1 - Data collection and model development
  - MODIS Land Products NDVI, LAI (Collection 4) 16 day for both sites 2000 - 2005
  - Field data; crop type, soil texture, climate, water use, yield etc.
  - Model testing; time step, resolution.
- Year 2 - Run Models on Test areas
  - Estimate water requirements and compare to field water use data.
- Year 3: Model Extension for input to economic models

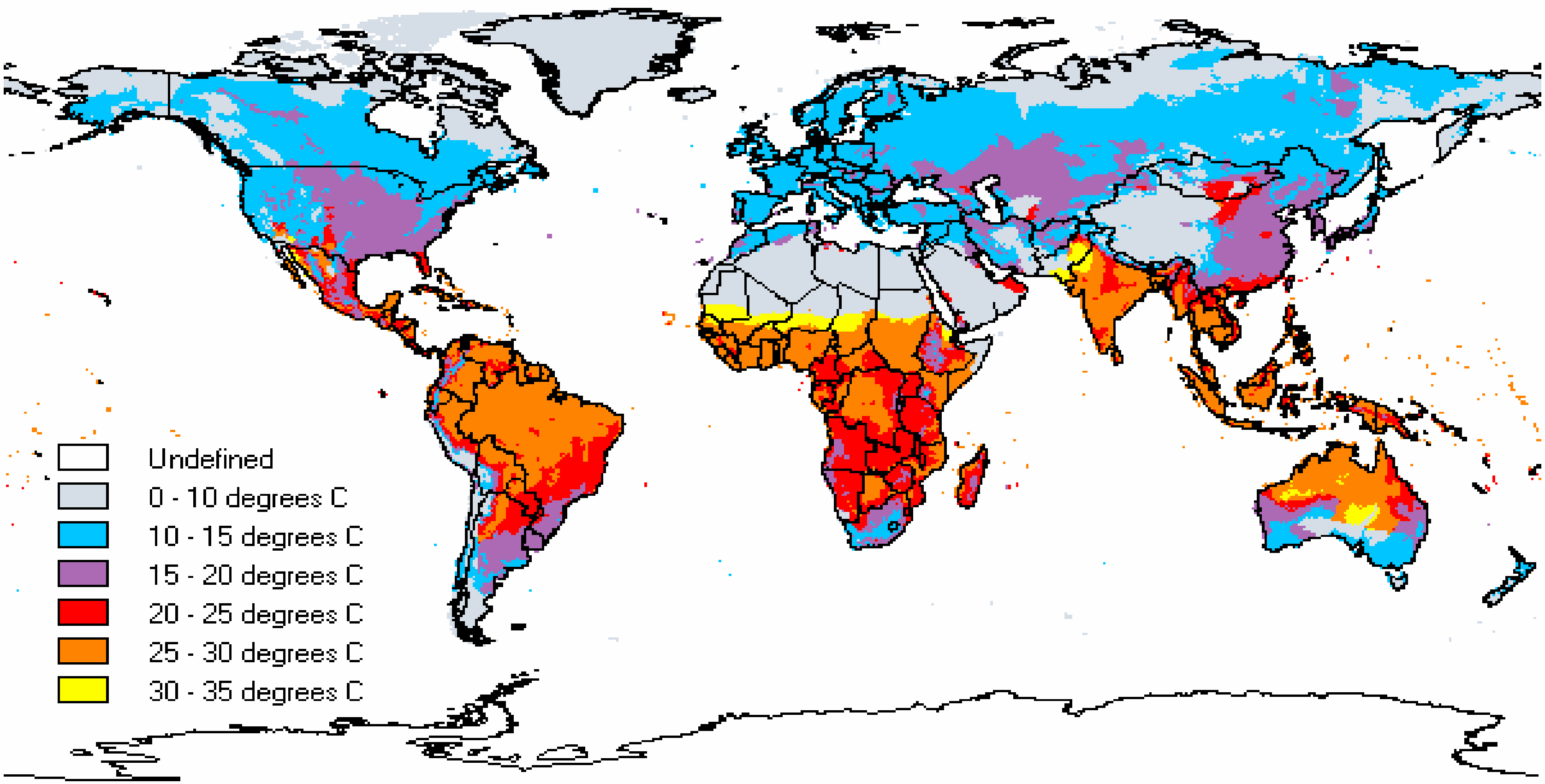
Irrigated Agro-Ecological Zones in 1997

Derived from: University of East Anglia. Climate Research Unit. *CRU05 0.5 Degree 1901-1995 Monthly Climate Time-Series*. East Anglia, Great Britain.



Rainfed Thermal Regimes in 1997

Derived from: University of East Anglia. Climate Research Unit. *CRU05 0.5 Degree 1901 -1995 Monthly Climate Time -Series*. East Anglia, Great Britain.



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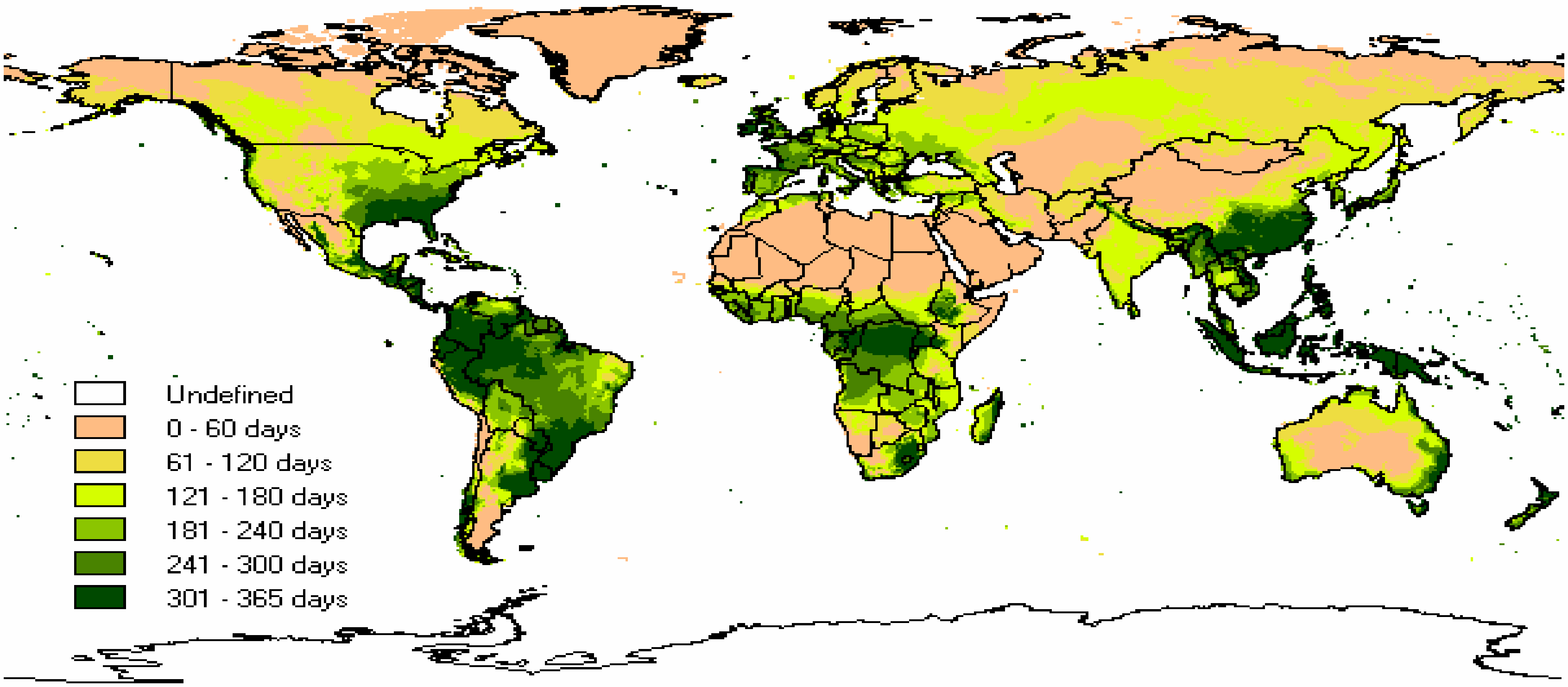
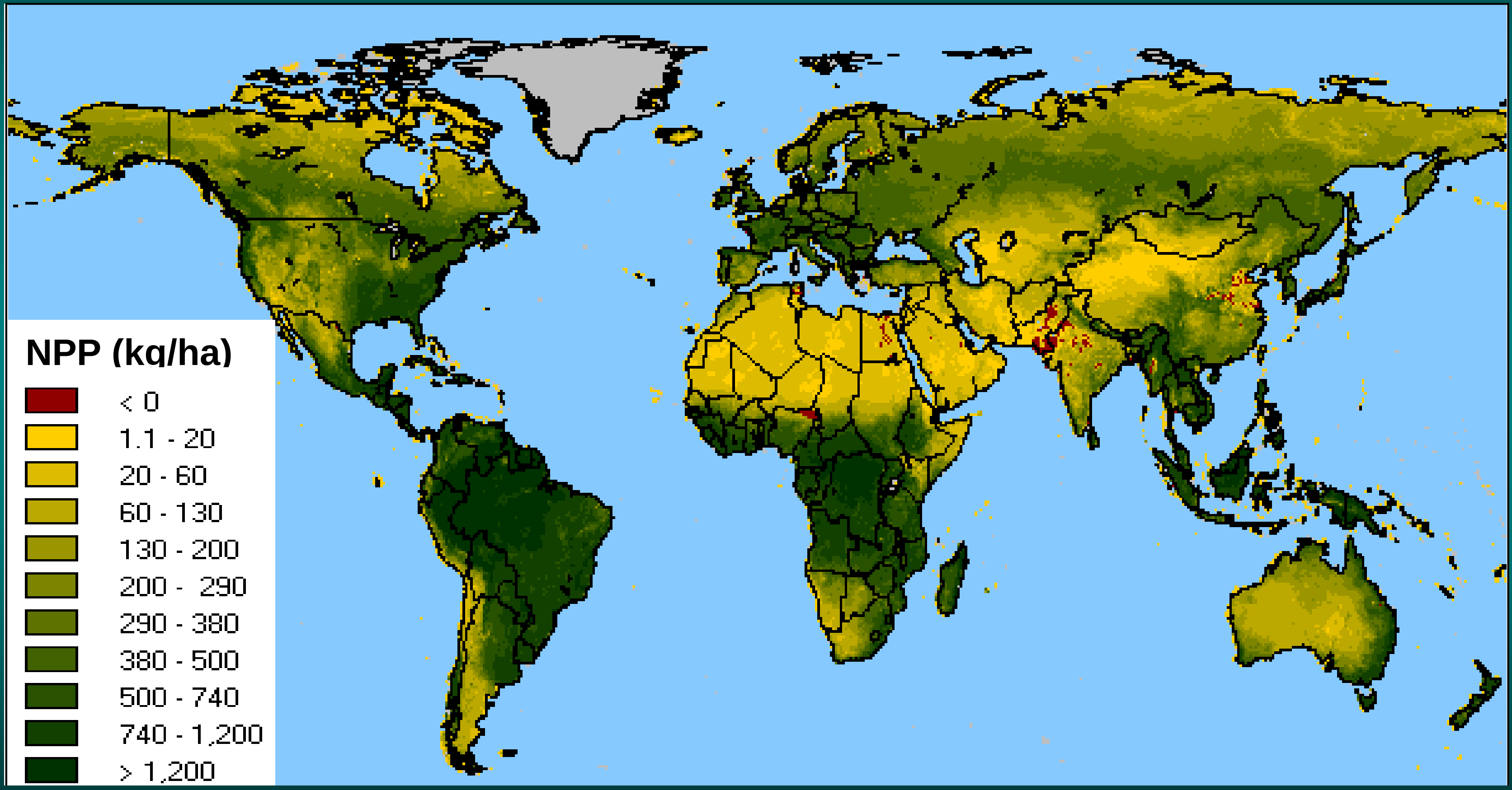
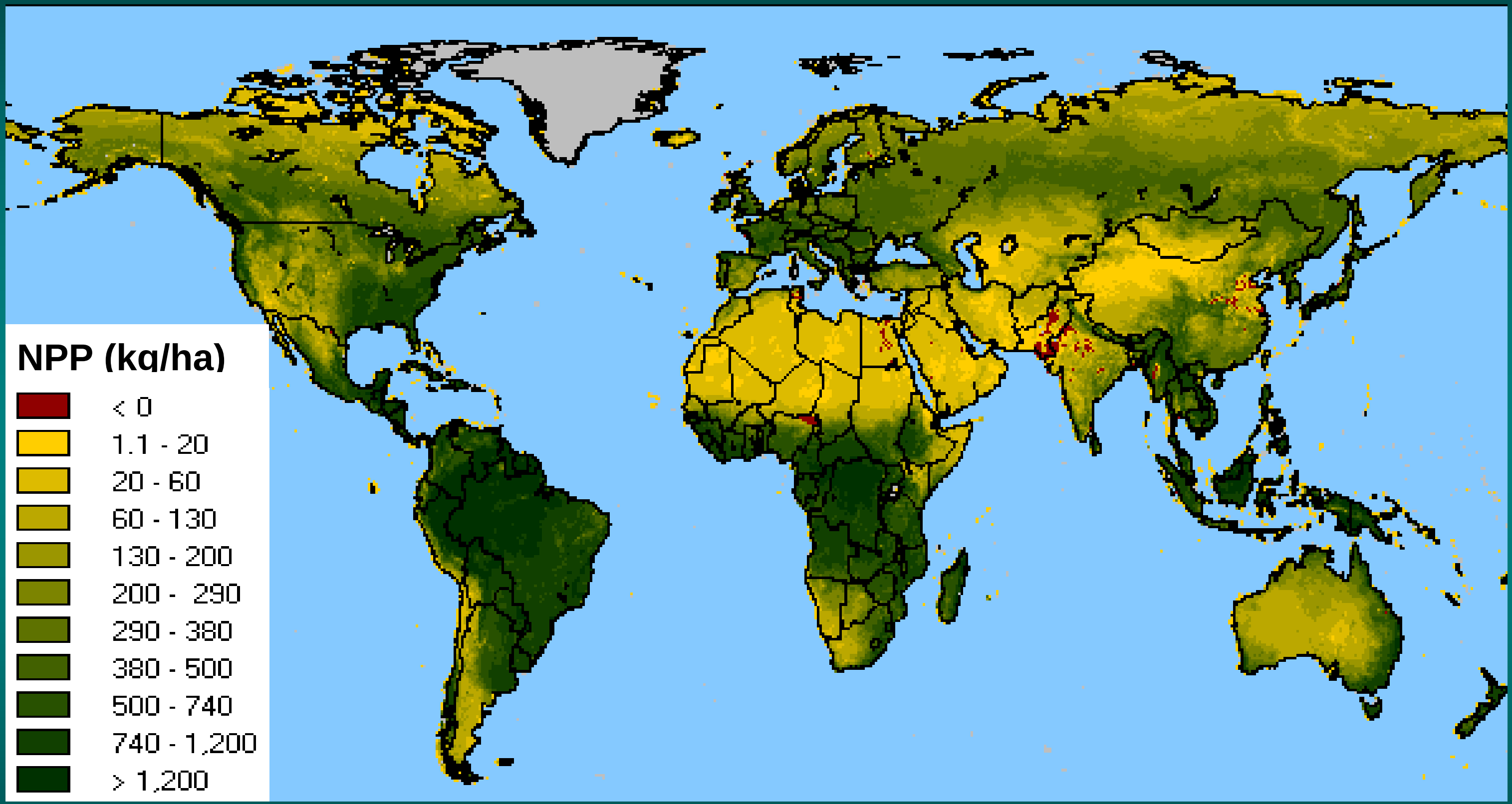
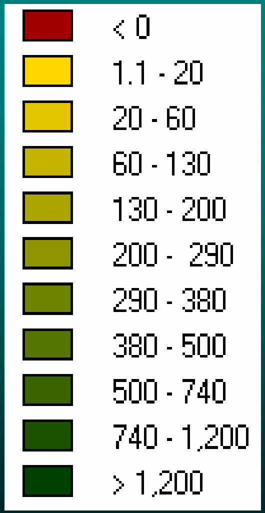


NPP Remaining After Harvest




NPP (kg/ha)
< 0
1.1 - 20
20 - 60
60 - 130
130 - 200
200 - 290
290 - 380
380 - 500
500 - 740
740 - 1,200
> 1,200



< 0
1.1 - 20
20 - 60
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2003 wet year,
2004 average,
2006 - droughty

Test site: 37.92 N and 58.57 E
Near Annau - 15 minutes from Ashkhabad.

003 wet year,
004 average,
006 - droughty

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ear Annau - 15
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shkhabad.