SAND2015-4805C

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A Regional Model of Human Migration and Climate Change Effects

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2015 IMISCOE Annual Conference, Geneva, Switzerland

June 27, 2015

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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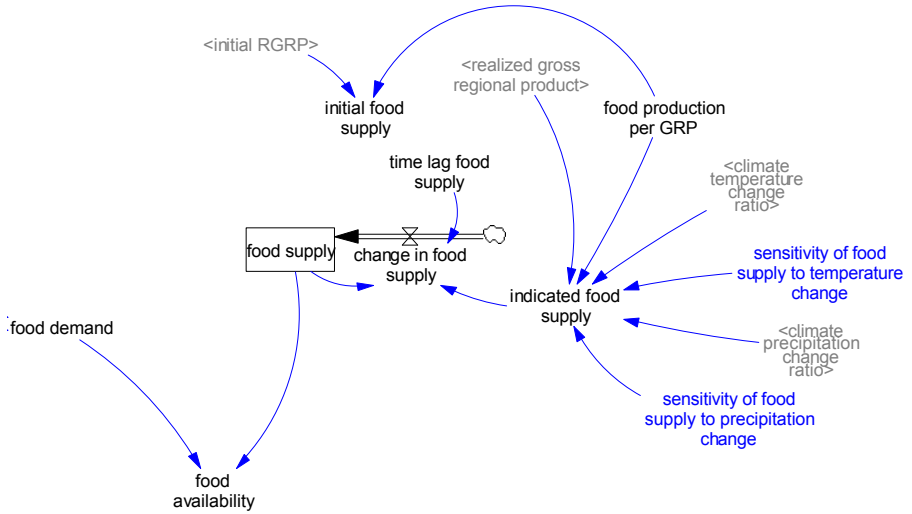
Problem Concept and Objectives

- Changing climatic conditions are likely to place increased stress on vulnerable populations through:
  - intensifying damage to homes and critical infrastructure,
  - reduced food production,
  - compromised health and hygiene, and
  - land and environmental degradation.
- Deteriorating conditions increase pressure on internal and international migration.

Objectives

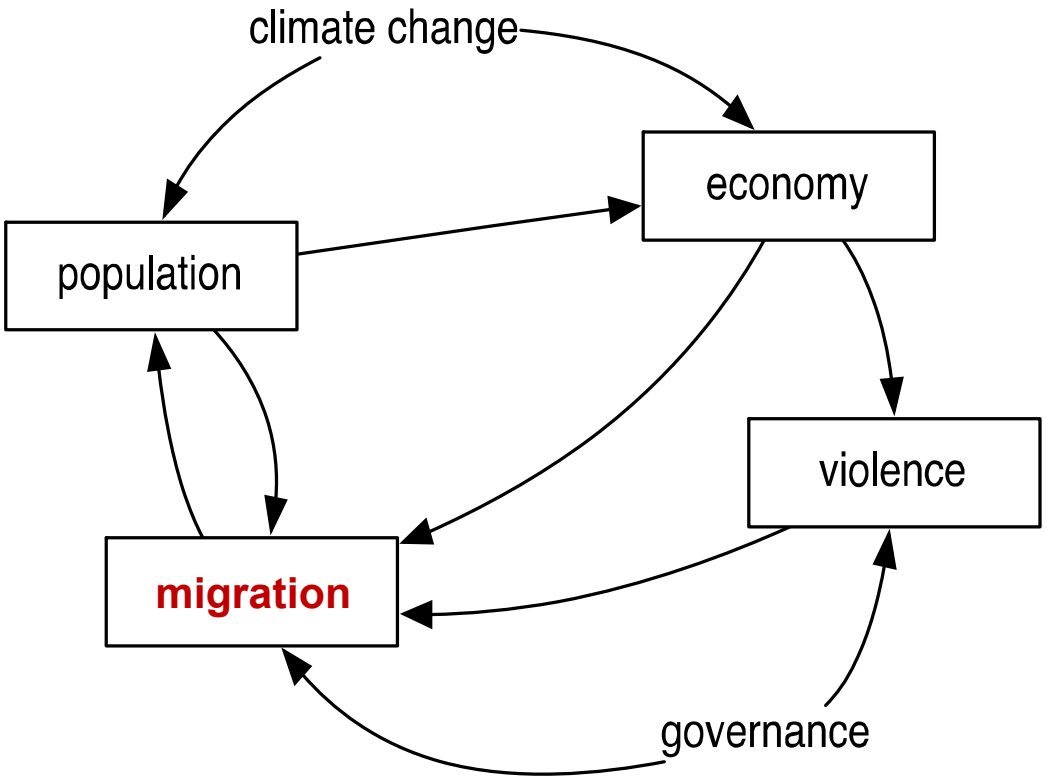
- Given the complexity of factors influencing human migration, quantitative tools are needed to aid policy analysis.
- Toward this need, a system dynamics-based model is developed that couples migration behavior with the interacting dynamics of:
  - Economy,
  - Labor,
  - Population,
  - Violence,
  - Governance,
  - Water,
  - Food, and
  - Disease.



- A regional model focused on Mali in western Africa has been adopted for the first test case.

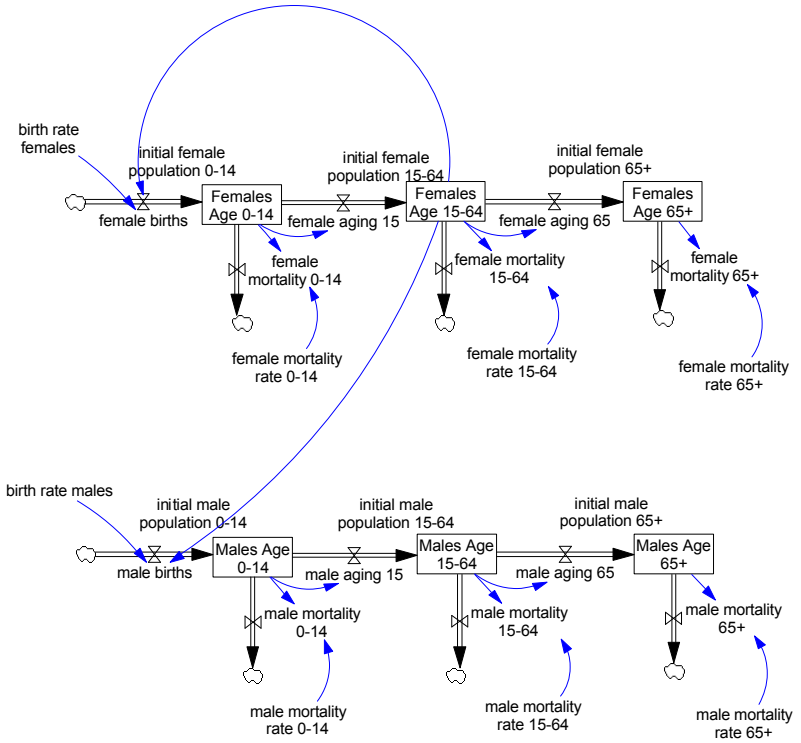
Model Framework

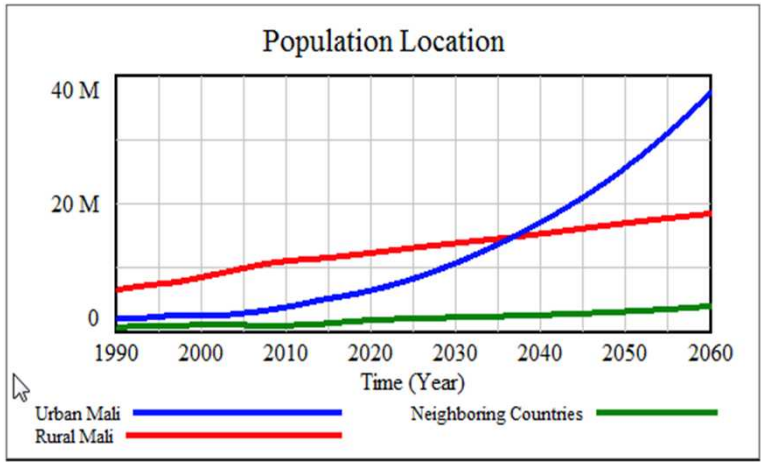
- Adopted a System Dynamics modeling architecture
- Model constructed in Vensim, version 6.3
- Migration currently influenced by interacting dynamics of:
  - Economics,
  - Violence,
  - Population,
  - Climate (exogenous), and
  - Governance (exogenous).
- Currently adding dynamics of:
  - Water, and
  - Food.



Population

- Population modeled as aging chain determined by dynamics of:
  - Births,
  - Mortality, and
  - Aging.
- Population distinguished by:
  - Gender,
  - Age group,
    - Age 0-14
    - Age 15-64; potentially productive work force
    - Age 65 and over
  - Labor type,
    - Skilled and
    - Common
- Initial growth rates calibrated to match historical data and projections (UN 2012).
- Birth and Death rates change as a function of location, income and violence





Economy

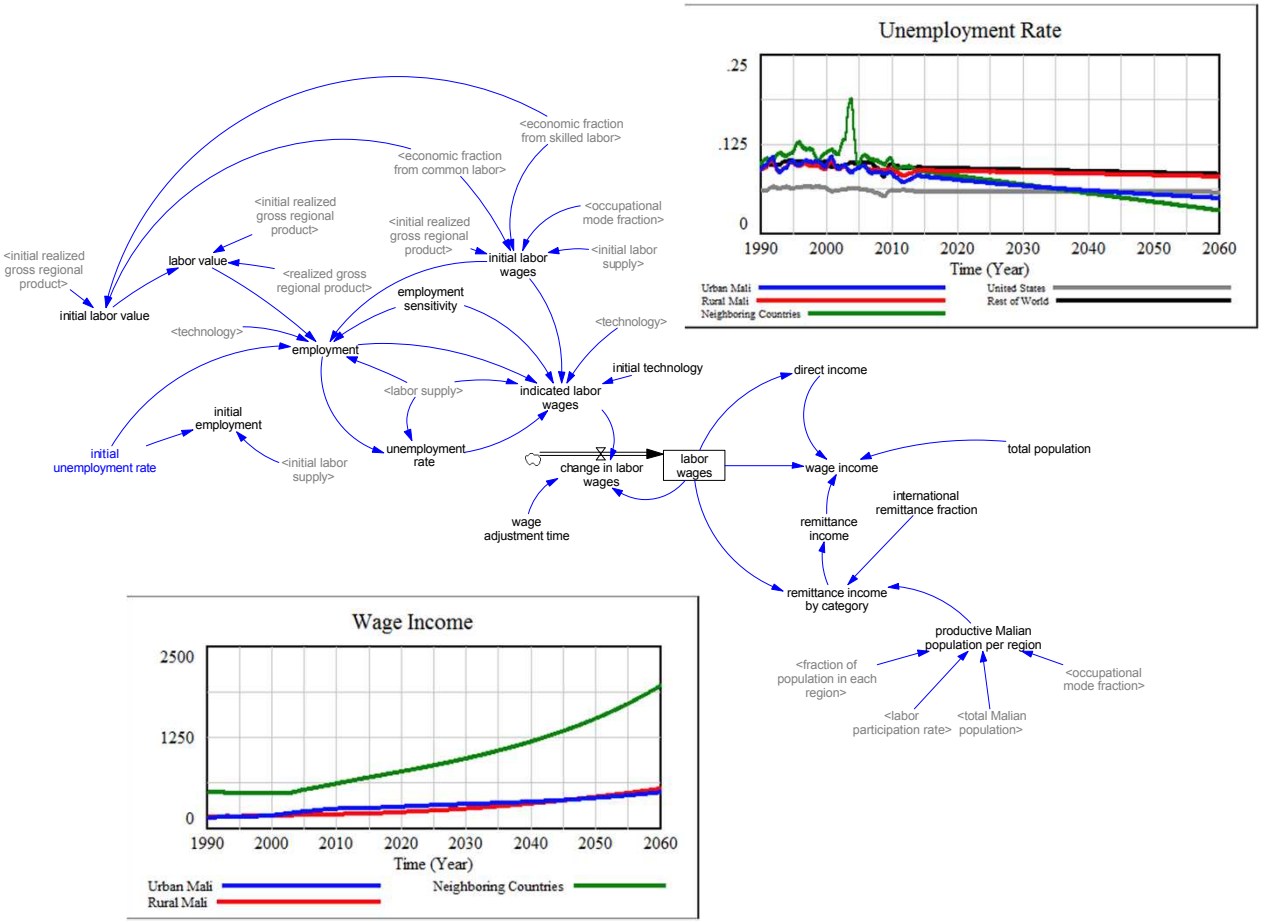
- Economic model based on Cobb-Douglas formulation.
- Gross regional product (GRP) is a function of labor supply, capital and technology.
- Realized GRP influenced by climate impacts on capital, land, labor and resources.
- Realized GRP along with population dynamics determine labor and wage dynamics.
- Base case calibrated to IPCC 2000, scenario B2.

Gross Regional Product

$$PGRP_i = PGRP_0 * \left(\frac{LS_{i,s}}{LS_{0i,s}}\right)^{LsF_i} * \left(\frac{LS_{i,c}}{LS_{0i,c}}\right)^{LcF_i} * \left(\frac{C_i}{C_{0i}}\right)^{CF_i} * \left(\frac{TK_i}{TK_{0i}}\right)^{(LcF_i+LsF_i)}$$

Realized Gross Regional Product

$$RGRP_i = PGRP_i * {EC_i}^{\alpha_i} * {EG_i}^{\beta_i} * {EL_{s,i}}^{\gamma_i} * {EL_{c,i}}^{\delta_i} * {RA_i}^{\epsilon_i} * {GG_i}^{\mu_i} * {GI_i}^{\sigma_i}$$



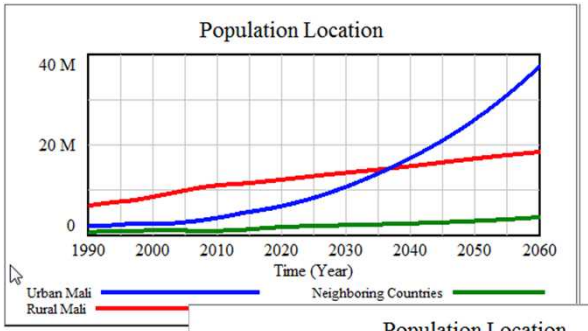
Migration

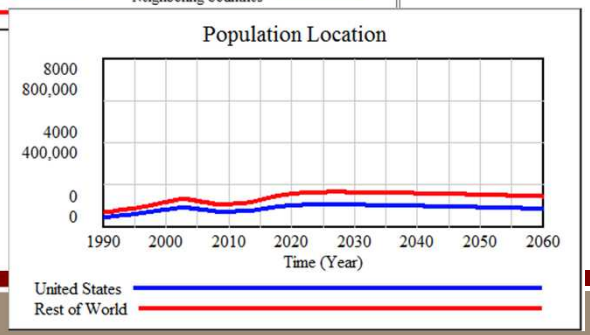
Utility Function

$$MU_{i,l,g,v} = \alpha_{i,l,g,v} + \beta_{1i,l,g,v} * \ln\left(\frac{WI_i}{WI_{0i}}\right) + \beta_{2i,l,g,v} * \ln\left(\frac{FA_i}{FA_{0i}}\right) + \beta_{3i,l,g,v} * \ln\left(\frac{GG_i}{GG_{0i}}\right) + \beta_{4i,l,g,v} * \ln\left(\frac{GI_i}{GI_{0i}}\right) + \beta_{5i,l,g,v} * \ln\left(\frac{DM_i}{DM_{0i}}\right) + \beta_{6i,l,g,v} * \ln(VI_i) + \beta_{7i,l,g,v} * \ln(II_i) + \beta_{8i,l,g,v} * \ln(FI_i) + \beta_{9i,l,g,v} * \ln\left(\frac{UER_{i,l}}{UER_{0i,l}}\right) + \beta_{10i,l,g,v} * \ln\left(\frac{POP_{i,x,l,g,m}}{POPx_{l,g,m}}\right) + \beta_{11i,l,g,v} * \ln(NDI_t)$$

Behavioral Intension

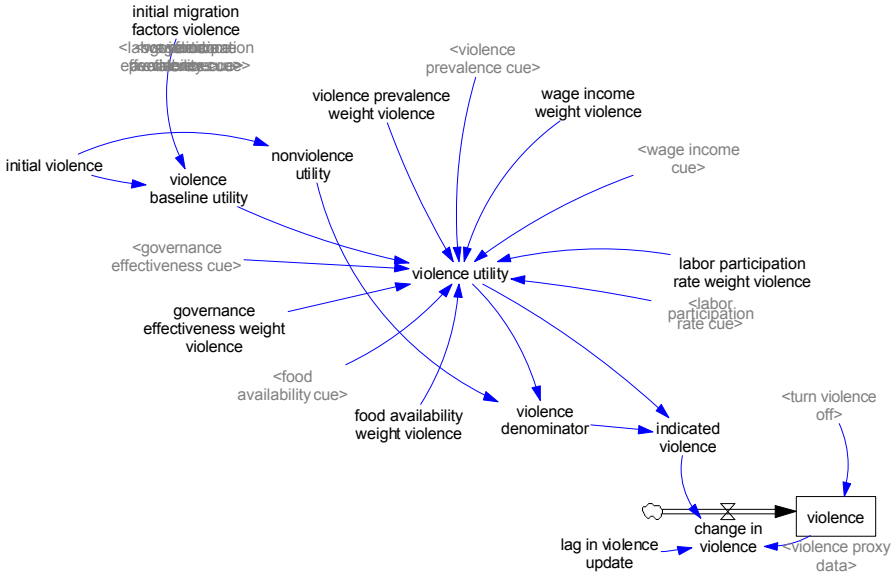
$$MP_{i,l,g,v} = Exp(MU_{i,l,g,v}) / \sum_k Exp(MU_{k,l,g,v})$$

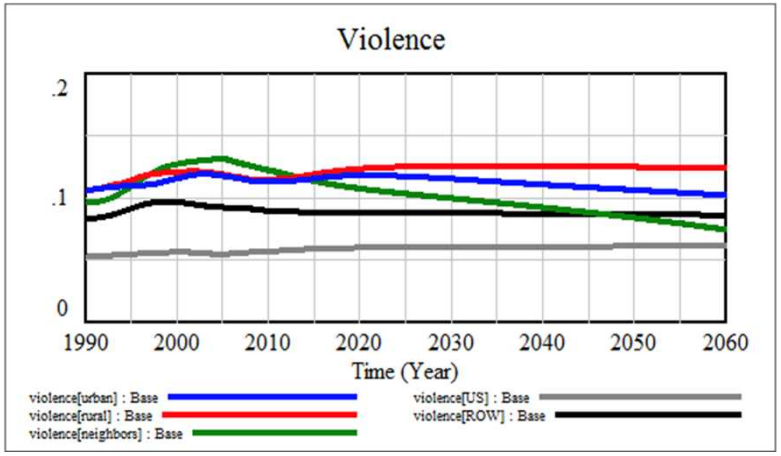




- Migration decision dynamics follow a cognitive formulation based on qualitative choice theory.
- Determine fraction of target population that chooses to live in the following destinations (or return home):
  - Urban,
  - Rural,
  - Neighboring country,
  - United States, or
  - Rest of World.
- Migration influenced by:
  - Income,
  - Food availability,
  - Governance effectiveness,
  - Violence,
  - Unemployment,
  - Natural disaster, and
  - Population
- Weights for the utility function are determined through calibration.

Violence

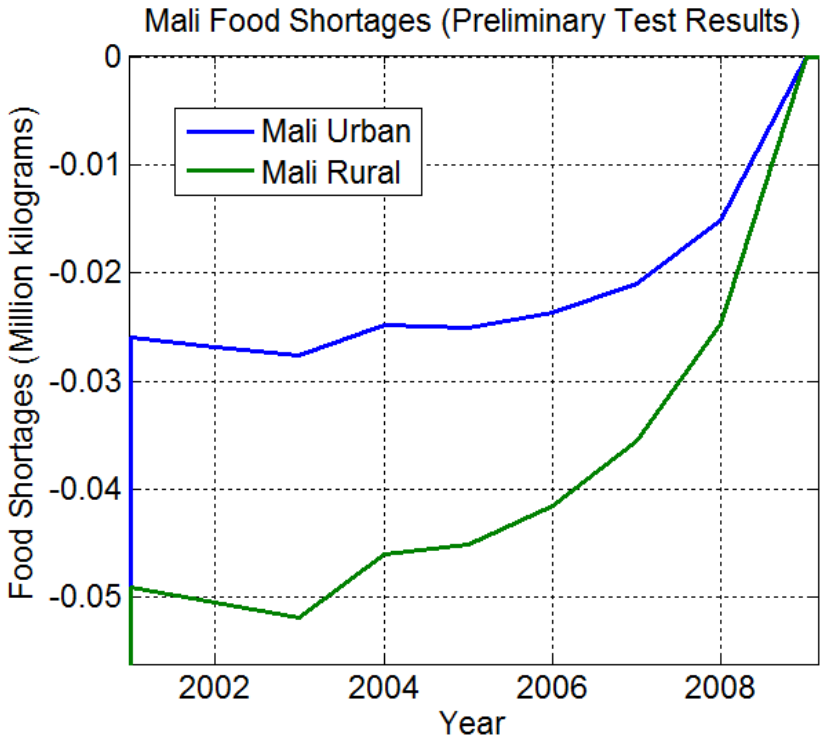


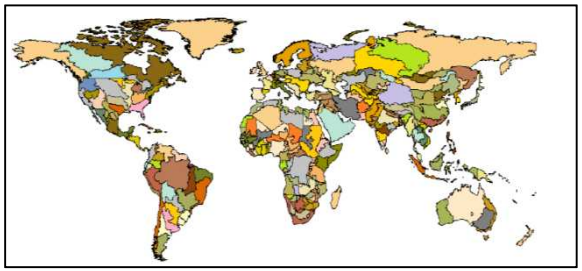


- Violence dynamics follow a similar approach as used for migration.
- Violence influenced by:
  - Income,
  - Food availability,
  - Governance effectiveness,
  - Unemployment, and
  - Migration.

Food and Water Modeling

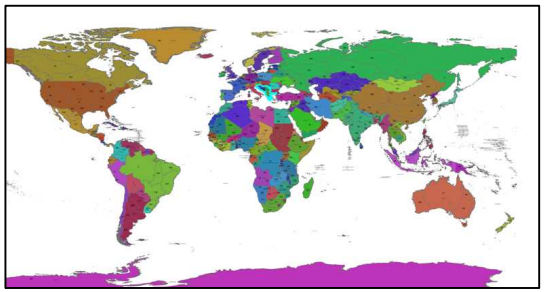
- The migration model has linkage to higher fidelity food and water models:
  - University of Illinois World Water Model determines impact of climate change on water availability.
  - IFPRI World Food Model determines the impact of water availability and climate change on food production, supply, demand, trade, and price.
  - Migration model data for population, GDP, labor wages, and capital affect consumption and production of food.





<=Food Production Areas

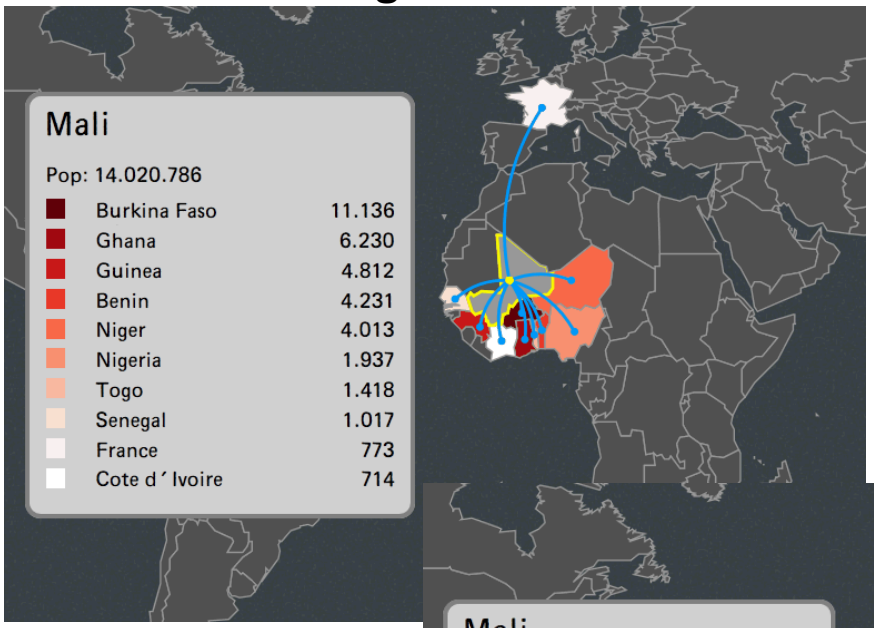
River Basins =>



*IFPRI = International Food Policy Research Institute

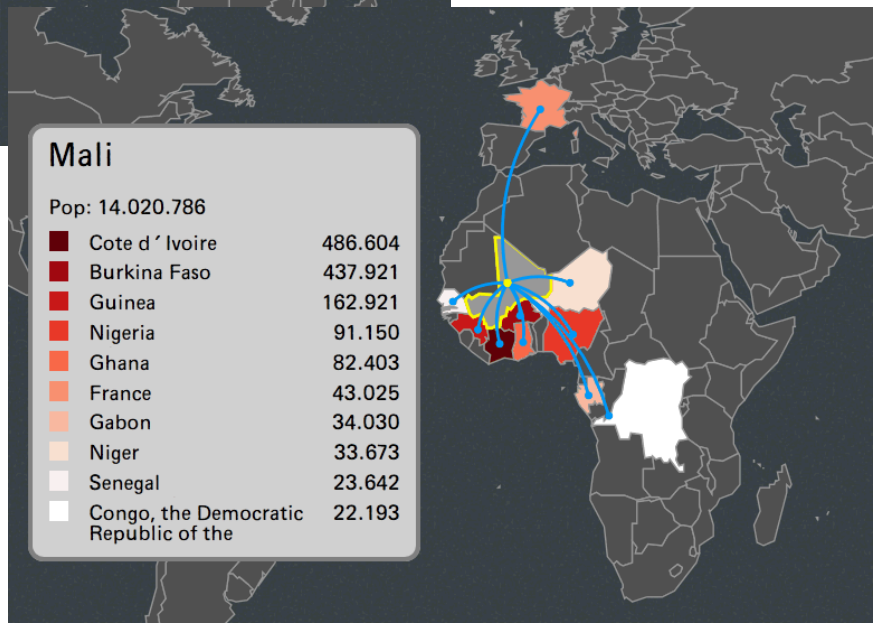
Test Case: Mali

In Migration



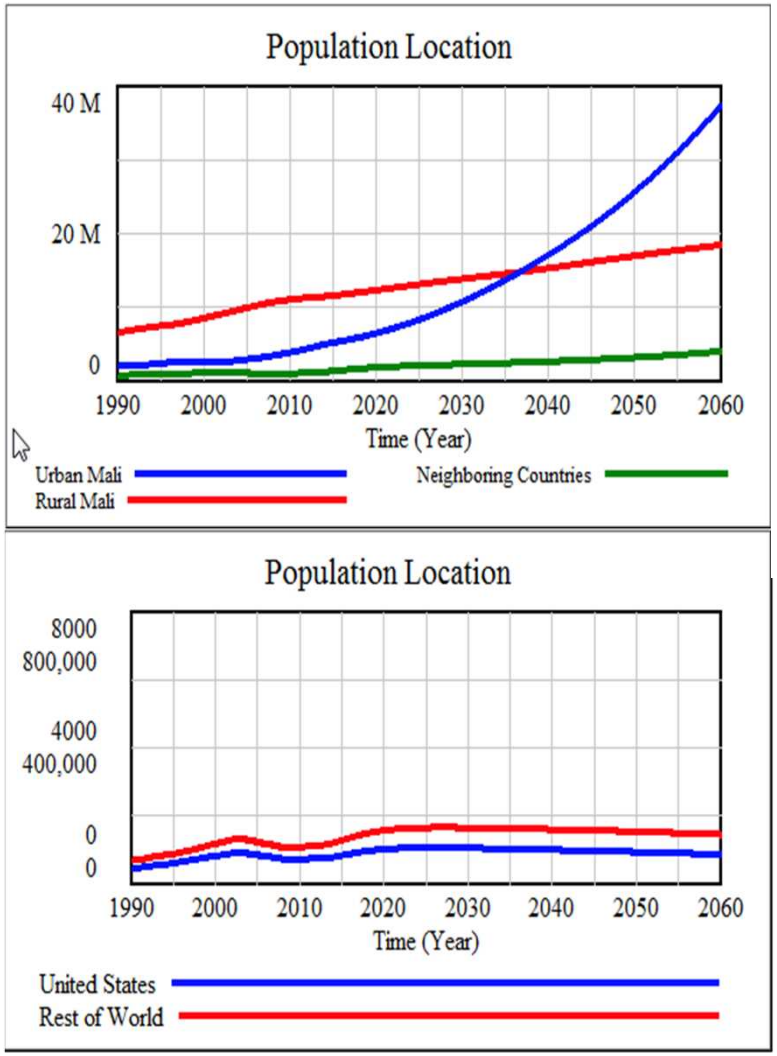
www.migrationsmap.net

Out Migration



- Mali has a long history marked by migration.
- Subject to intense droughts.
- Also recently plagued by conflict.
  - Migration Scenarios:
    - Base Case (IPCC 2000, scenario B2)
    - Climate Change (increase in temperature)
      - Mali: 1.25° C
      - Neighbors:1.25° C
      - U.S.: 2° C
      - ROW: 1.5° C

Results: Base Case

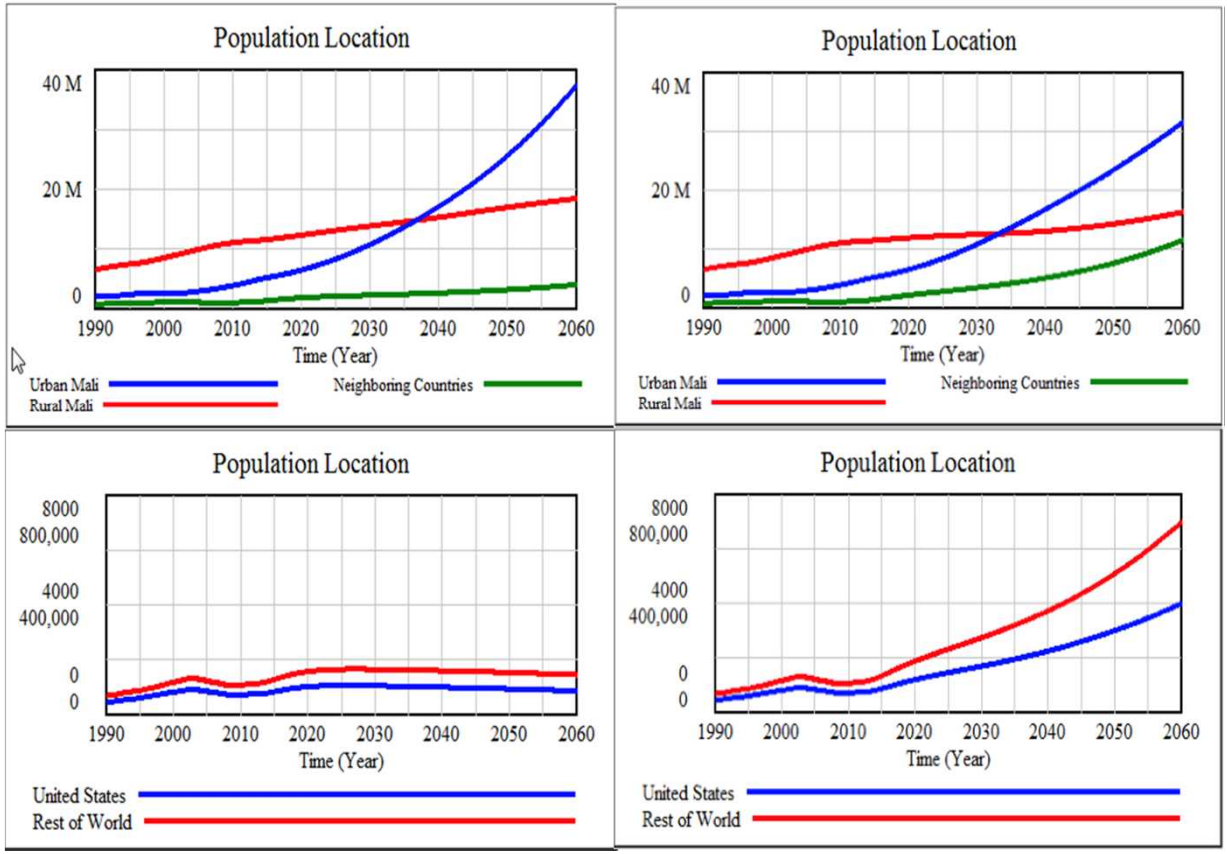


- Rapid population growth projected for Mali
  - From ~17M in 2015 to ~65M in 2060
  - Urban population overtakes rural population in 2037
- Slow rise in migration to neighboring countries, while migration shows a slow decrease to U.S. and ROW after 2020.
- Migration grows as smaller rate than population.

Results: Climate Change

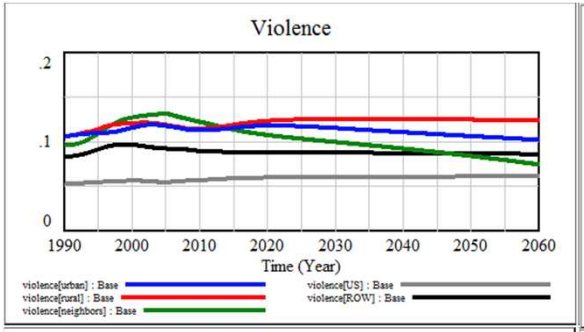
- Rising temperature impacts are seen in:
  - Reduced population growth for both rural and urban,
  - Clear increase in migration to neighboring countries, U.S. and Rest of World

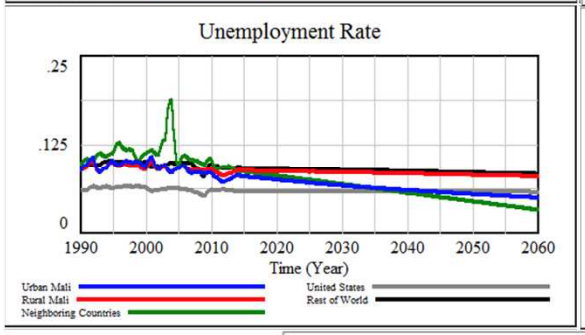
Base Case | **Climate Change Case**



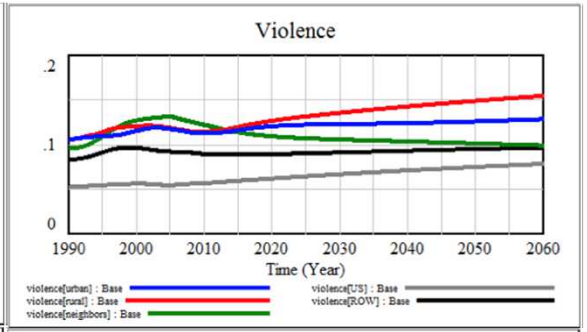
Results: Migration Drivers

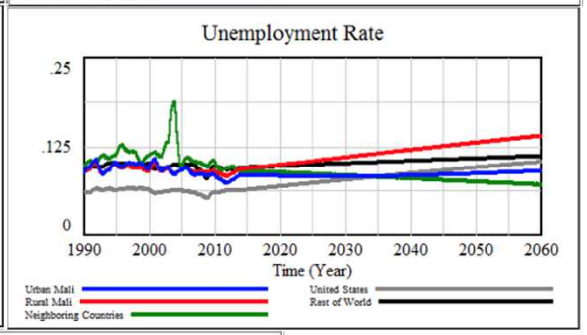
Base Case

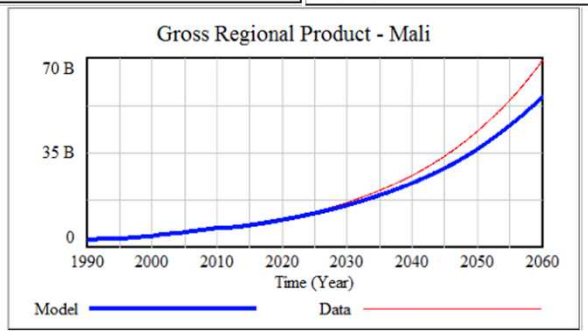




Climate Change Case

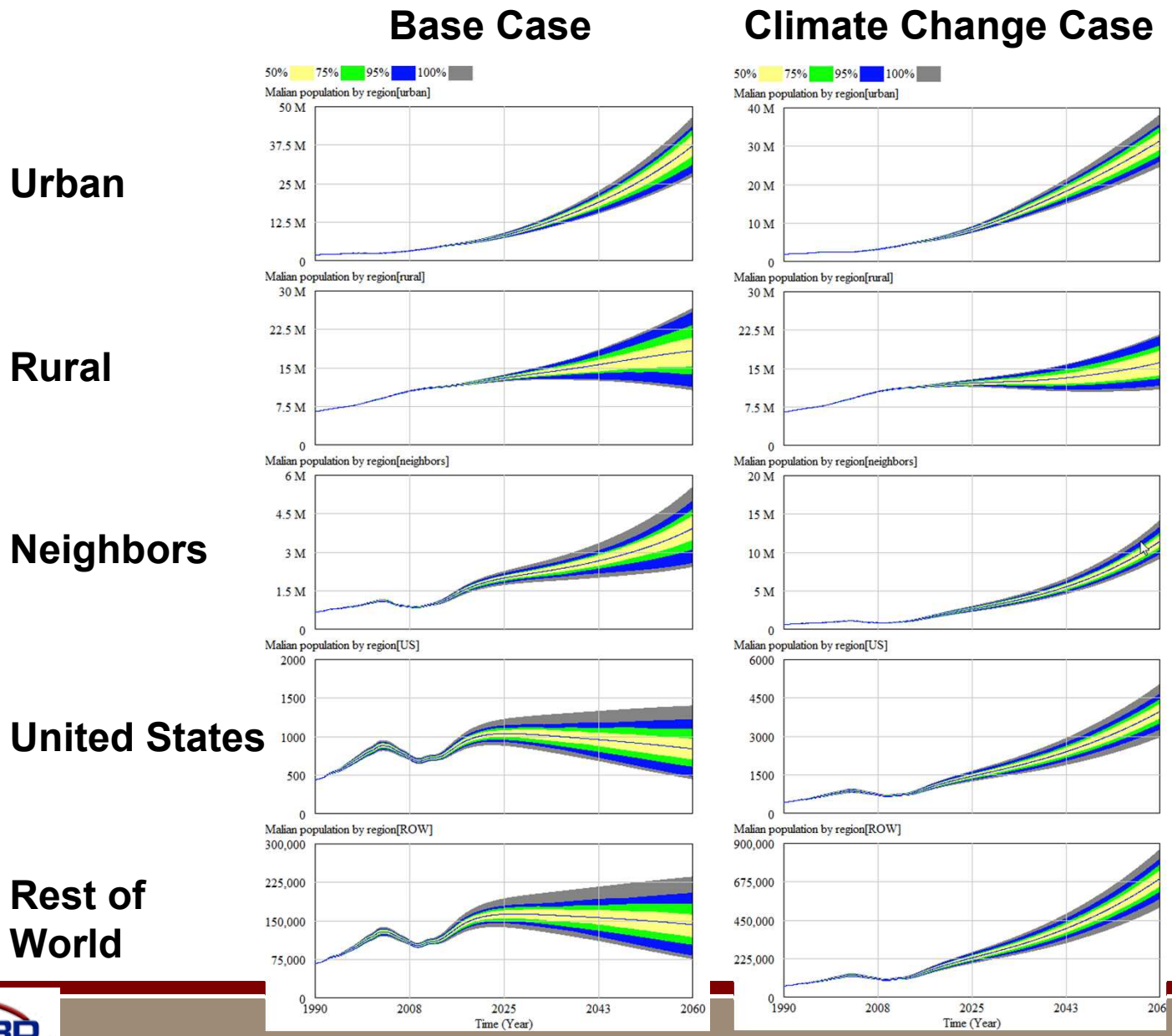






- Related impacts to rising temperatures:
  - Increase in violence,
  - Increasing unemployment, and
  - Decreasing gross regional product.

Migration Sensitivity



Summary

- Climate change poses an aggravating factor toward human migration.
- Developed a system dynamics-based model that couples migration behavior with the interacting dynamics of economy, labor, population, violence, governance, water, food, and disease.
- Rising temperatures are seen to have interacting effects on
  - Migration,
  - Violence,
  - Unemployment, and
  - Gross Regional Product.