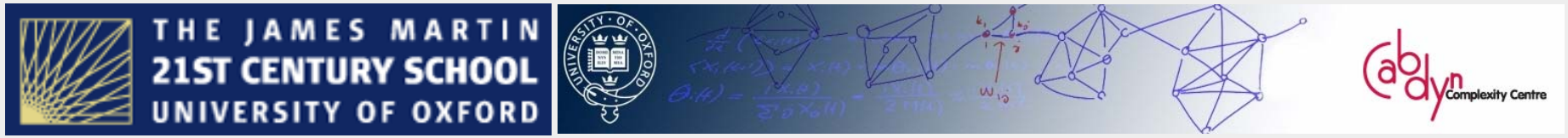

Seminar Series Hilary Term 2010
"Complexity and Systemic Risk"

Anticipating Future Complexity:

Models for Understanding and Forecasting Futures for Cities

Michael Batty
University College London

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http://www.casa.ucl.ac.uk/

Outline

- About Urban Models: Different Types, Styles, Many Different Conceptions of Cities
- Key Challenges
- *Symbolic Models*: Land Use Transportation Interactions: LUTI Models for Greater London
- *Iconic Models*: Visualising City Form
- Blending and Integrating Urban Models: Unanticipated Consequences

About Urban Models: Different Types, Different Styles, Different Conceptions of Cities

Many types of models – essentially mathematical or physical and this depends on the degree of abstraction

The more the abstraction, the less physical or real

Classifications: broadly into iconic and symbolic

Iconic – the focus is on representation, often superficial

Symbolic – the focus on structures and processes, on dynamics and change: mathematical modelling

The history of our field is that the early beginnings of modelling in the 1950s were essentially symbolic models using the numerical processing power of early computers

And gradually the physical has come to be modelled using CAD

There is now a massive mix of styles involving the entire spectrum of representations from highly symbolic math representations of cities to highly physical, from urban economic theory to empirical functionalism

There are also conceptual differences between what in cities should and/or can be ‘modelled’ or ‘simulated’,, and there are conceptual models that do not make any attempt at empirical verification,

Here we will focus one style of model that is verifiable in some sense, within the existing classical scientific method – observation, tuning/calibration, verification, validation by taking the model elsewhere to see if it performs, and then forecasting/prediction. But even this type of classical science is up for grabs because of overwhelming variety and complexity

There are at least three classes of symbolic urban model – generic types

Aggregative, static land use transport models (LUTI) using ideas from urban economic theory and social physics to simulate flows and locational activity

Disaggregate, dynamic generative models of a physical type which focus on development and morphology like CA models

Individual models – agent based models that focus on the dynamics of individual spatial choice, microsimulation

Key Challenges

Models originally focussed on urban growth and transportation but the focus is rapidly changing to consider key issues of *Climate Change* - based on rising sea levels, heat islands and so on, and *Energy Change*, the current obsession with fossil fuels and their depletion, *Demographic Change* – aging and the changing balance of economic support and health care, *Environmental Degradation*, through pollution, and to an extent *Regeneration*

There is now wide recognition that all issues cannot be captured in one model.

Symbolic Models: Land Use Transportation Interactions: LUTI Models for Greater London

We will spend a lot of time on traditional urban models – LUTI – and not on generative or ABM models, although complexity theories tend to be more focussed on these latter modelling styles and types. On generating urban activity from the bottom up

But first some background on what our Greater London model is all about

We are concerned in this model with long term prediction – climate change out 50 to 100 years from now, aging, transitions in energy use and transport technology

In general, the longer the time horizon for prediction, the greater the uncertainty that detail in the model is required. Longer time horizons perhaps mean simpler models. It is complicated enough as you will see.

More robust models are needed and there is little point in developing very detailed and intricate models which require huge data resources.

Hence we are using equilibrium models of how people make locational decisions where we assume the system adjusts over long time periods

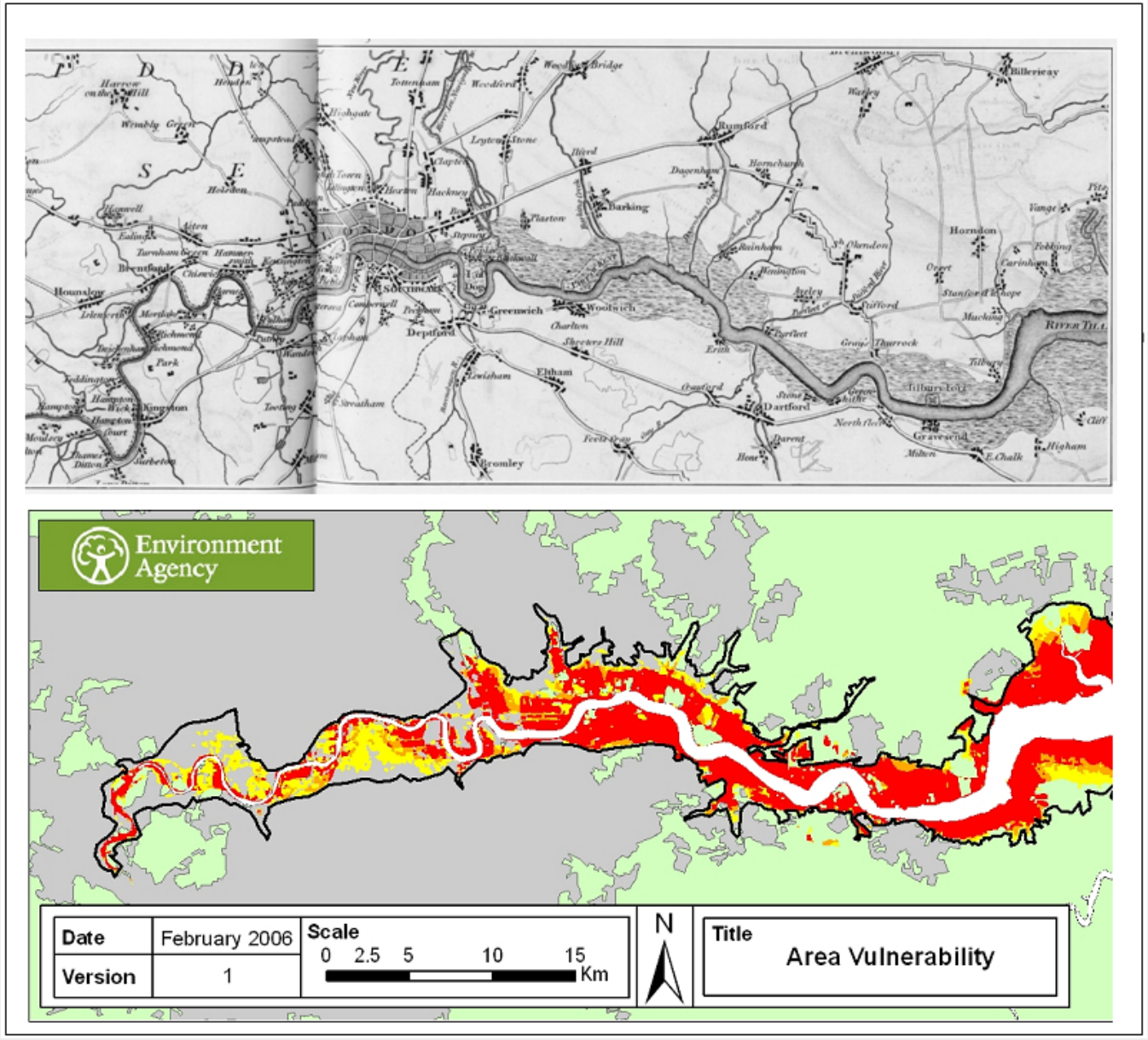
For 50 to 100 years, there are well known if not well established predictions of physical change – climate change, in our case, rising sea levels.

Thus the model is comparative static – to forecast small area population change that we assume adjusts over 50 or 100 years. Contestable yes

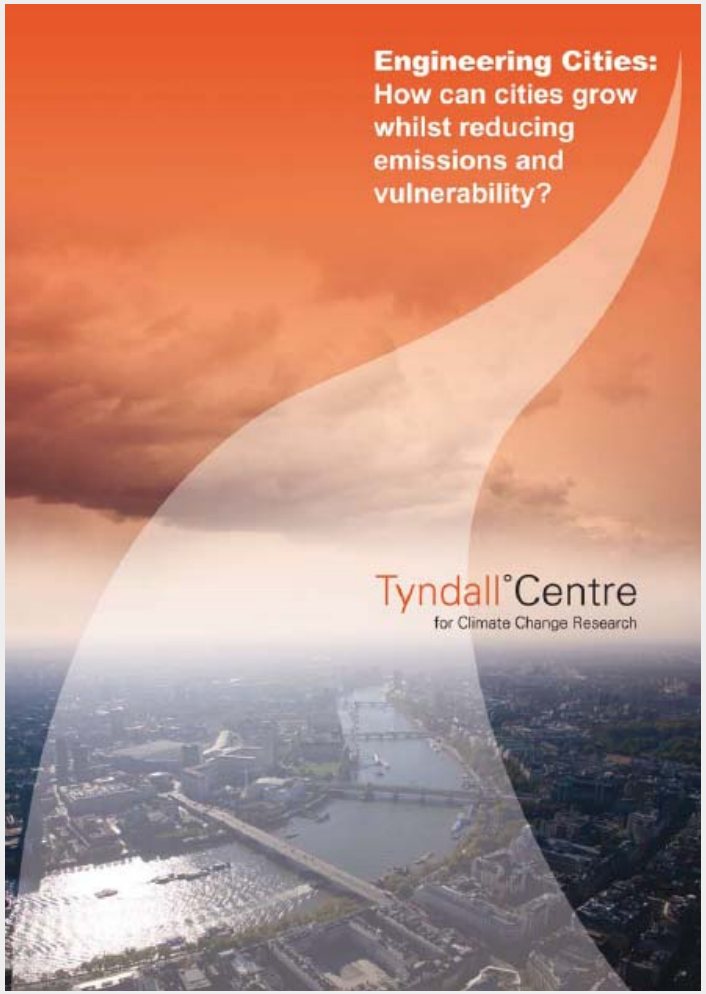
The model also needs to be intelligible to a wide variety of professionals and experts and we use extensive visualisation of how these things work

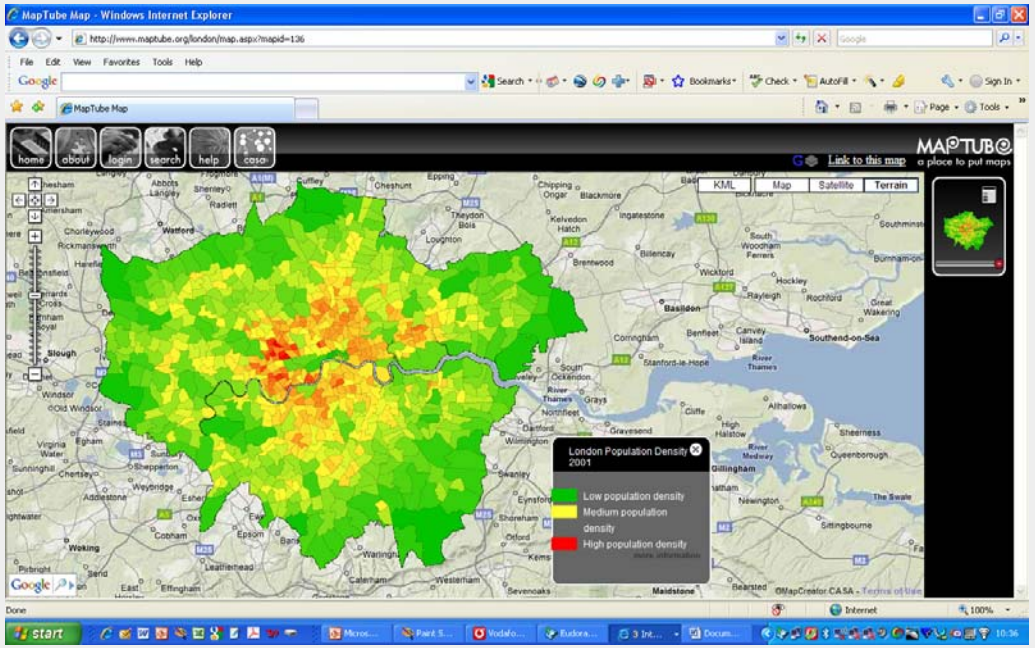
First a few words about the model and its context being part of the Tyndall Cities project

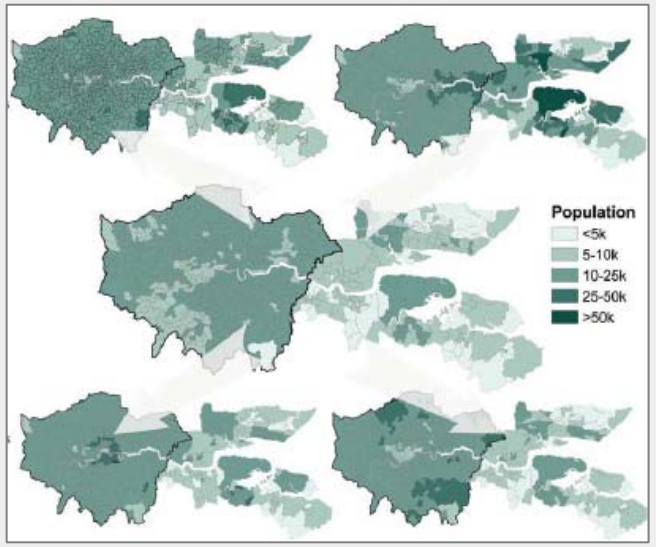
We chose London because of significant flood risk and because of complementary studies of London involving air pollution, urban form, the heat island effect etc. all funded through EPSRC


Environment Agency
Date
February 2006
Version
1
Scale
0 2.5 5 10 15
Km
N
Title
Area Vulnerability

The Context: *Climate Change in London: Flooding & Pollution*
Mainly along the River Thames and Its Estuary

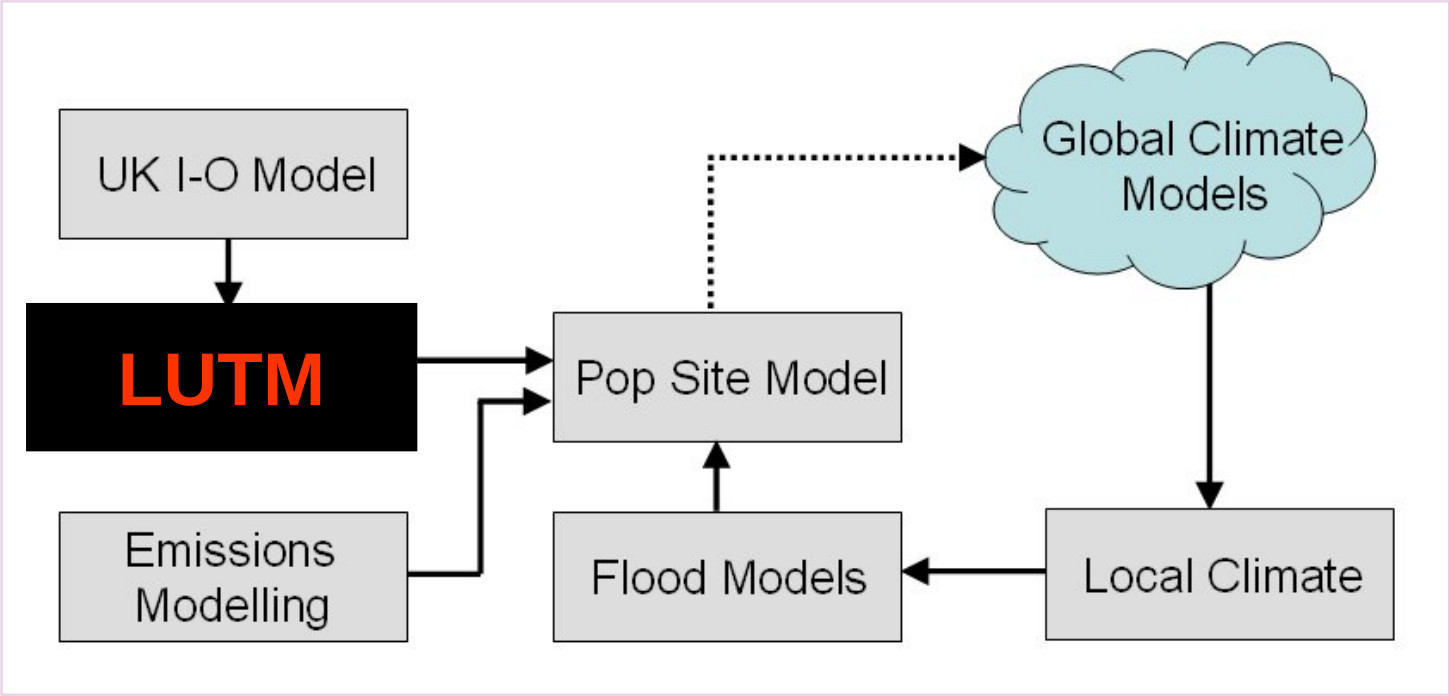






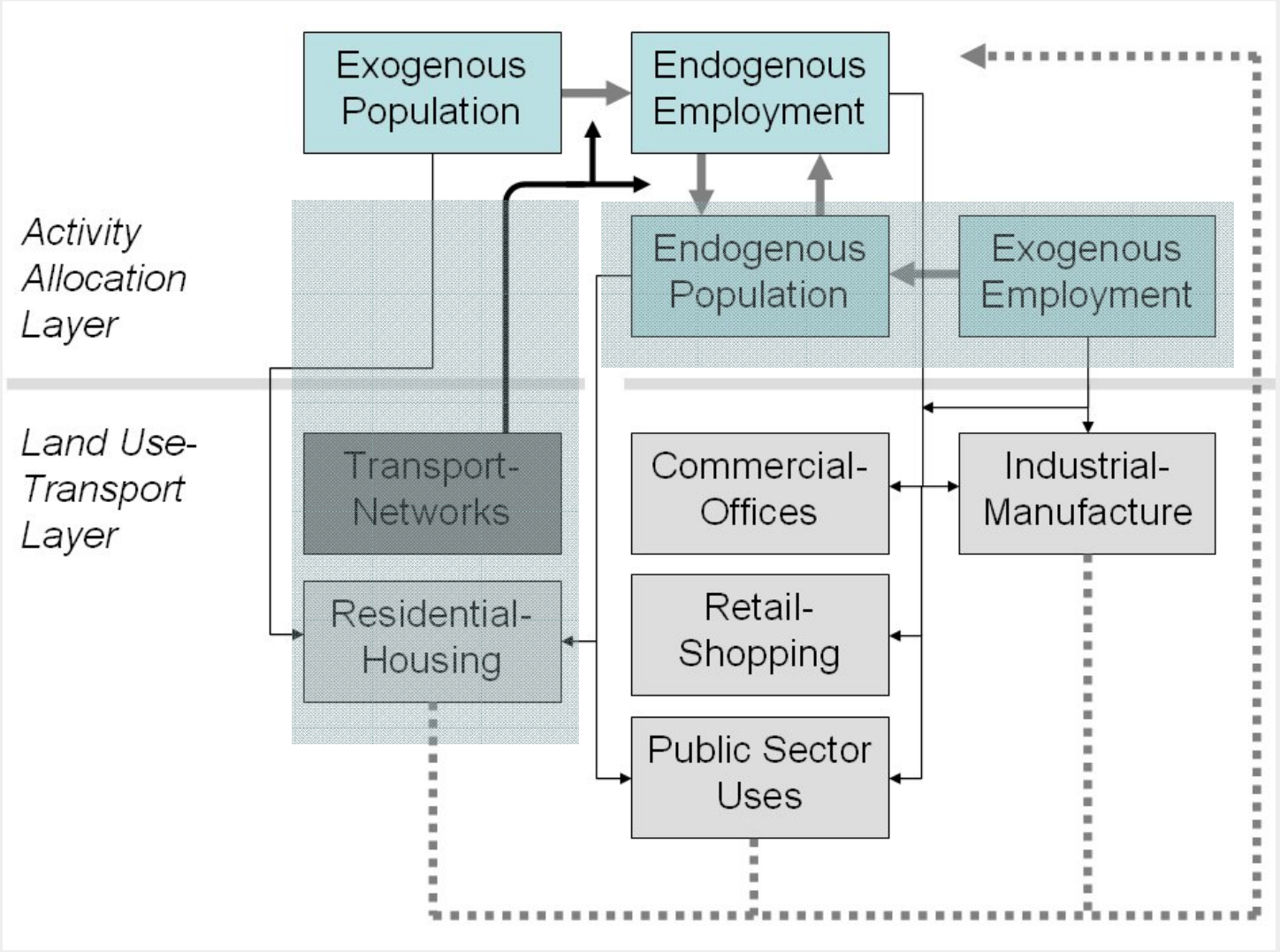
The GLA consists of 33 boroughs, 633 wards and 7.7m population and we will forecast population at the finest scale

The model sits lies at the core of a process of chaining models together built by different groups and coming from different traditions



The LUTM is in two layers – activity allocation and physical location

The Land Use Transport Model



The model is simple, highly visual – so that any informed expert can use it or at least it can be demoed easily.

It is strongly coupled into GIS as mapping is central to the visualisation – in fact all the GIS is purpose built. It is accessible, immediate and capable of being demoed quickly

It is quite different from many of the current large scale LUTM models like UrbanSim, more aggregate

But first something about its structure – I will focus on the residential model as this is typical of the way we are extending it to other sectors

Structure of the Residential Location Model

- The existing model is formulated as a four mode residential location model, origin constrained but subject to capacity constraints, with competition between locations and modes of travel determined respectively by floorspace availability and travel costs
- The capacity constraints are introduced exogenously and can be formulated as policy levers but this as in all such model application introduces a degree of arbitrariness.

- The algebraic formulation is as follows. I will define terms as I verbally introduce this. Note that $i,\ j, \& \ k$ are origin (employment), destination (population) zones and modes (road, bus, rail and tube)

$$T_{ij}^{k} = A_i O_i F_j \exp(-\lambda^k c_{ij}^k)$$

$$D_j = \sum_{ik} T_{ij}^{k}$$

Subject to the following constraints

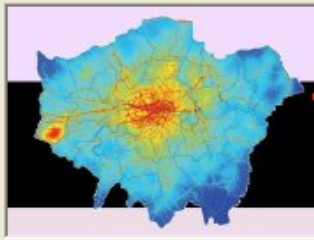
$$\sum_{jk} T_{ij}^{k} = O_i$$

$$\sum_{ij} T_{ij}^{k} c_{ij}^{k} = \overline{C}^{k}$$

- The modes are road, bus, heavy rail and light rail (Tube and DLR)
- There is no disaggregation but five employment, five population groups are identified in a future model
- The model is calibrated to mean trip costs
- The model is visually driven and can be used to set up simple scenarios in an integrated desktop environment.

To give a flavour of the model, I will show some screen shots first before I run it …..

London and the Thames Gateway Land Use Transportation Model



Cities Research Programme

Tyndall Centre for Climate Change Research

CASA@UCL Newcastle

This program is a rudimentary land-use transportation model built along classical lines which allocates population and employment to small zones of the urban system. It uses spatial interaction principles which bind the population sector (residential or housing) to employment sector (work or industrial and commercial) through the journey to work (work trips) and the demand from services (which loosely translate into trips made to the retail and commercial sector).

The model is being built for Greater London and the Thames Gateway at ward level - 633 in all - so that it can be used in a wider process of integrated assessment focussed on assessing the impact of climate change on small areas in this metropolitan region. In particular rises in sea level and pollution are key issues, and as such the model sits between aggregate assessments of environmental changes associated with global and regional climate change models and environmental input output models, and much more disaggregate models related to the detailed hydrological implication of long term climate change.

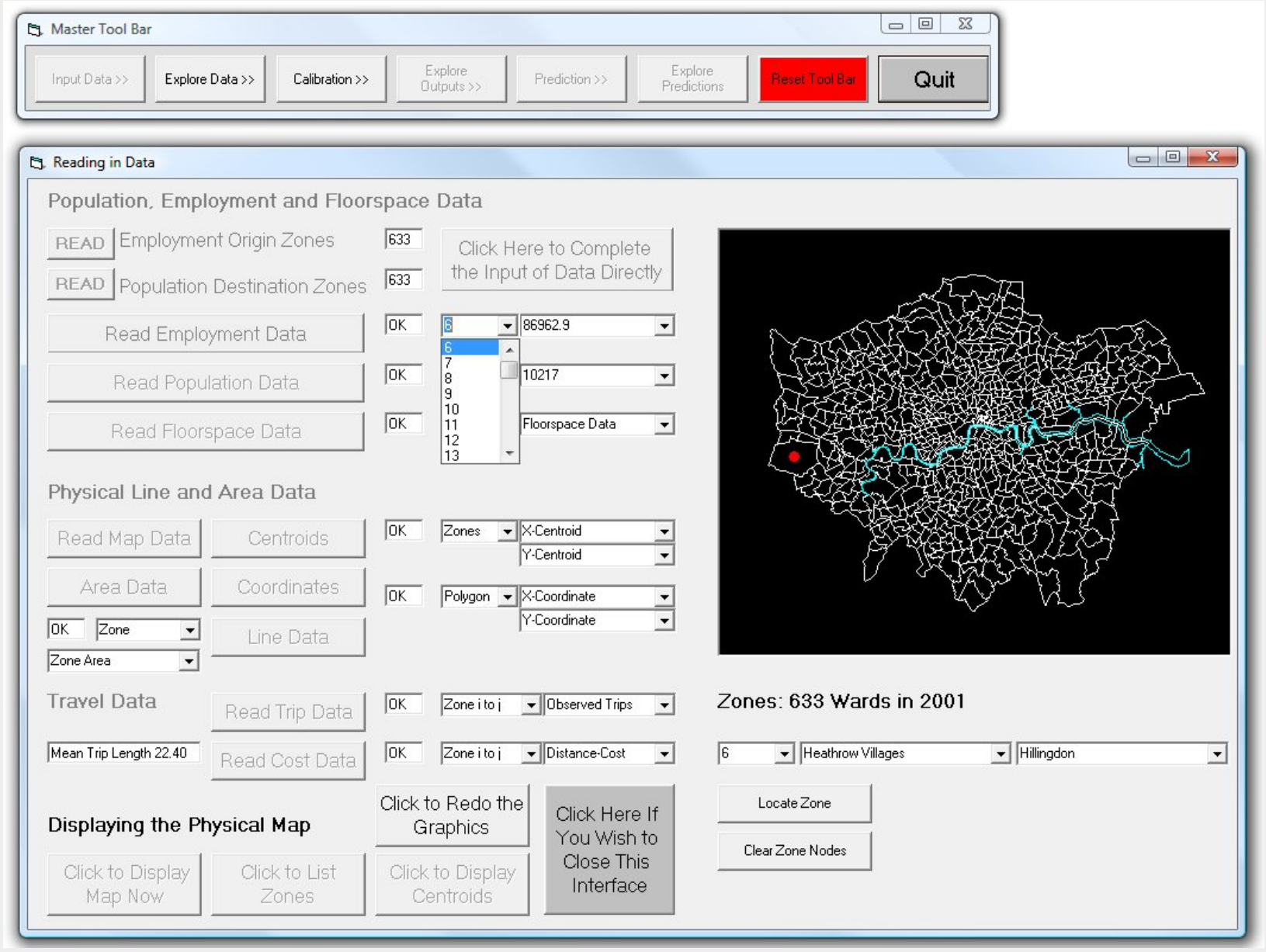
The programme enables the user to read in the data and explore it spatially, to calibrate the parameters of the model and explore its outputs spatially and to engage in various predictions ranging from the typical' business as usual scenarios' to much more radical changes posed limits on spatial behaviour which either result from climate change and, or mandated by government. The predictions and scenarios are intended to go out to 2100 and thus the model is largely designed as a sketch planning tool.

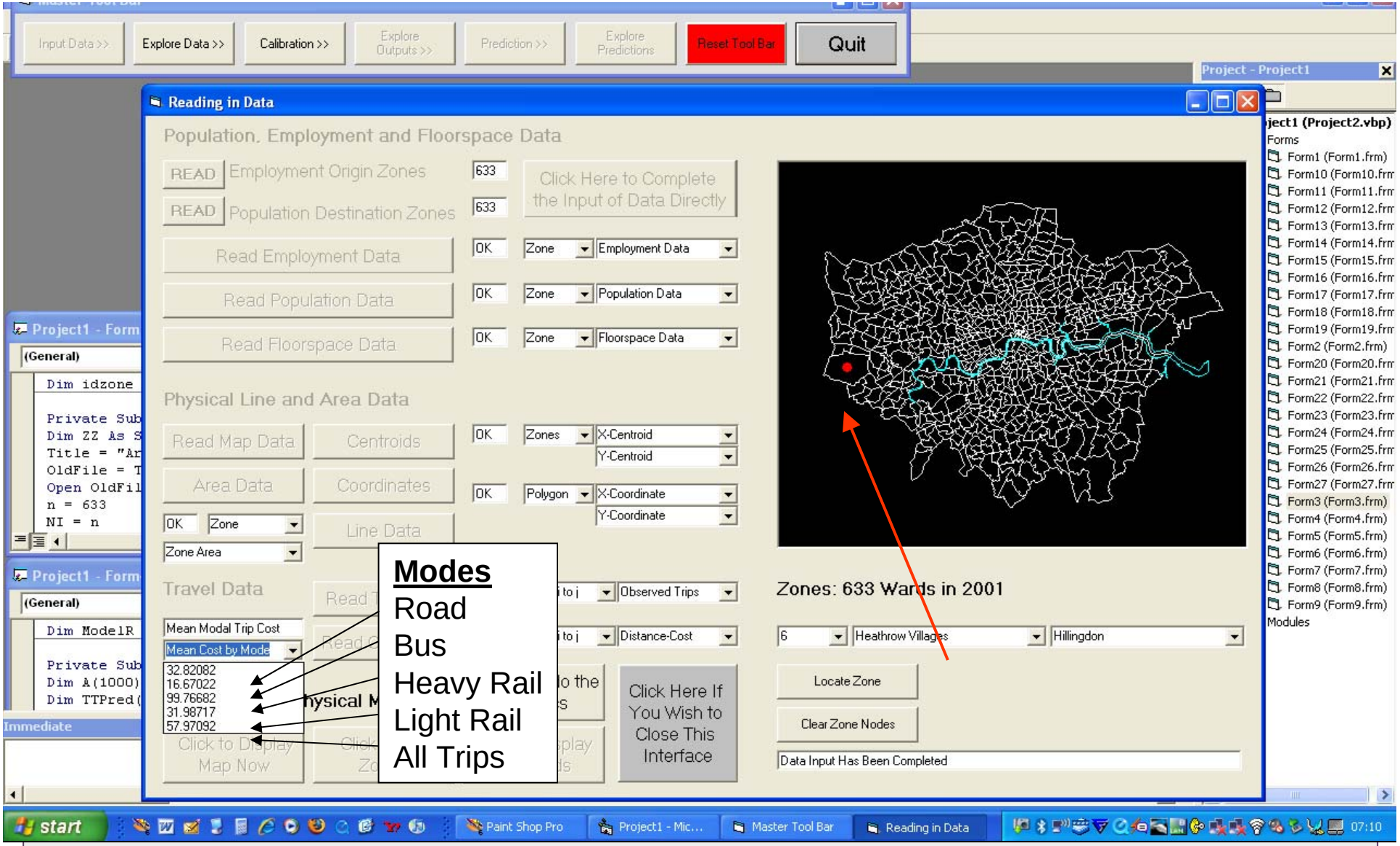
These various stages of the model contained in a master tool bar which is activated when the GO! button is pressed on this screen. The master tool bar enables the users to proceed through the various stages indicated and to display outputs in map and statistical form at any stage.

with GLAECONOMICS LONDON

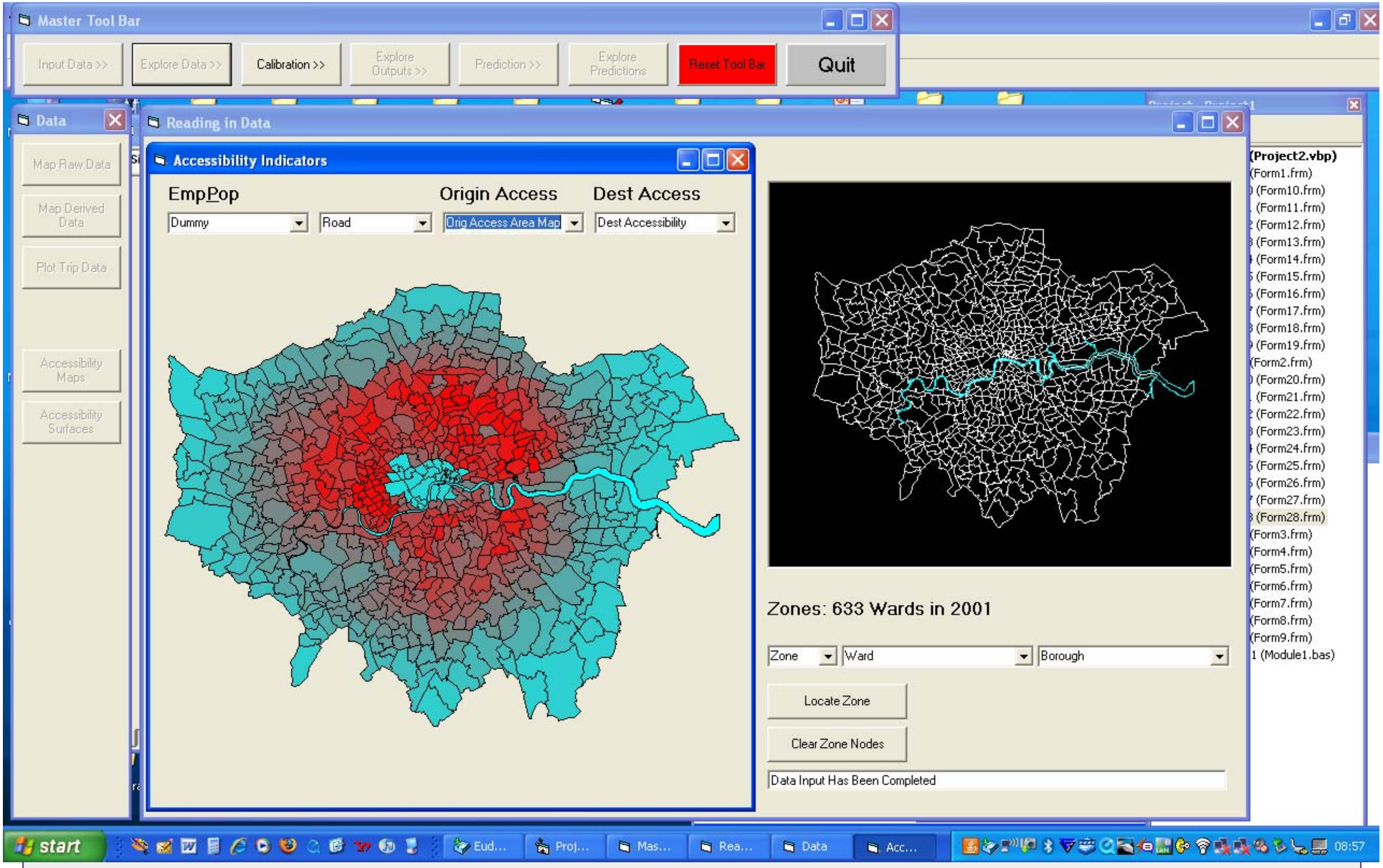
GO!

Program Manual


Master Tool Bar
Input Data >>
Explore Data >>
Calibration >>
Explore Outputs >>
Prediction >>
Explore Predictions
Reset Tool Bar
Quit
Reading in Data
Population, Employment and Floorspace Data
READ
Employment Origin Zones
633
READ
Population Destination Zones
633
Click Here to Complete the Input of Data Directly
Read Employment Data
OK
6
86962.9
6
7
8
9
10
11
12
13
Read Population Data
OK
10217
Read Floorspace Data
OK
Floorspace Data
Physical Line and Area Data
Read Map Data
Centroids
OK
Zones
X-Centroid
Y-Centroid
Area Data
Coordinates
OK
Polygon
X-Coordinate
Y-Coordinate
OK
Zone
Line Data
Zone Area
Travel Data
Read Trip Data
OK
Zone i to j
Observed Trips
Mean Trip Length 22.40
Read Cost Data
OK
Zone i to j
Distance-Cost
Displaying the Physical Map
Click to Redo the Graphics
Click Here If You Wish to Close This Interface
Click to Display Map Now
Click to List Zones
Click to Display Centroids
Zones: 633 Wards in 2001
6
Heathrow Villages
Hillingdon
Locate Zone
Clear Zone Nodes



Road: 38%; Bus: 12%: Heavy Rail: 12%: Light Rail 19%; Other (Walk, Bike, Fly): 19%


Master Tool Bar
Input Data >>
Explore Data >>
Calibration >>
Explore Outputs >>
Prediction >>
Explore Predictions
Reset Tool Bar
Quit
Data
Map Raw Data
Map Derived Data
Plot Trip Data
Accessibility Maps
Accessibility Surfaces
Reading in Data
Accessibility Indicators
EmpPop
Origin Access
Dest Access
Dummy
Road
Orig Access Area Map
Dest Accessibility
Zones: 633 Wards in 2001
Zone
Ward
Borough
Locate Zone
Clear Zone Nodes
Data Input Has Been Completed
(Project2.vbp)
(Form1.frm)
(Form10.frm)
(Form11.frm)
(Form12.frm)
(Form13.frm)
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(Form28.frm)
(Form3.frm)
(Form4.frm)
(Form5.frm)
(Form6.frm)
(Form7.frm)
(Form8.frm)
(Form9.frm)
1 (Module1.bas)
start
Eud...
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Data
Acc...
08:57

Master Tool Bar

Input Data >> | Explore Data >> | Calibration >> | Explore Outputs >> | Prediction >> | Explore Predictions | Reset Tool Bar | Quit

Predict

Input Scenario Data

Scenario from File

Employment Changes

Floorspace Changes

Distance Changes

Run Scenario Model

Run Model

More Scenario Runs ...

Expansion .....

Expansion .....

Expansion .....

Reading in Data

Prediction Routines

Long Term Scenarios Based on the Impact of Changes in Employment, Residential Floorspace, and Transport Costs

Predictions with the model involve forecasting the location of small area populations and the trip patterns associated with the four modes used to distribute employment as population to these small (residential) areas. This involves changing the input variables - employment and residential floorspace by small area, and the travel costs associated with each mode of transport, which in turn imply changes to the transport infrastructure. The user also has control over the parameter values on the friction of Travel Cost or travel cost associated with each mode. This can be changed in value to reflect changes in the average Travel Cost or cost travelled on each mode.

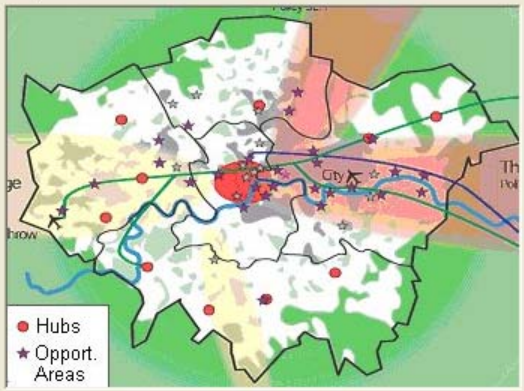
Users have a choice of inputting a preset scenario in which all these variables are changed exogenously or a process of changing these variables interactively, on screen. The interactive process can involve many thousands of changes and is probably best used to input data which reflects 'what-if' scenarios which require a small number of rather simple changes in the inputs reflecting substantial or radical change.

By clicking the 'Scenario from File' button in the toolbar to the left, a preset scenario is loaded and the user is then taken to the point where the model must be run. Alternatively if the user clicks the Employment Changes button, the user activates a screen where each employment zone can be identified by pointing the mouse at it and clicking. Then the user can use a slider bar to increase the value of employment in that zone by up to 100 percent or decrease it by up to 100 percent. As many zones as required can be changed using this method. When the user is satisfied with the employment scenario which has been developed, a button accepting these changes can be clicked. The same can then be done for floorspace activated by clicking the relevant button from the toolbar to the left.

Finally the travel cost on any link by any mode from one zone to another can be changed using the same method. An origin and then a destination zone need to be clicked and then reduced or increased travel cost (by up to 100 percent) made using the slider bar. The user must choose the mode each time and the program then recomputes all the shortest routes implied by these changes once the changes are accepted.

The user then proceeds to run the model as for the 'Scenario from File' option and once this is done, the outputs can be visualised using the same system for exploring the data and calibration results.

Key Elements of the London Plan to 2025 Shown Below.



(Project2.vbp)
(Form1.frm)
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(Form4.frm)
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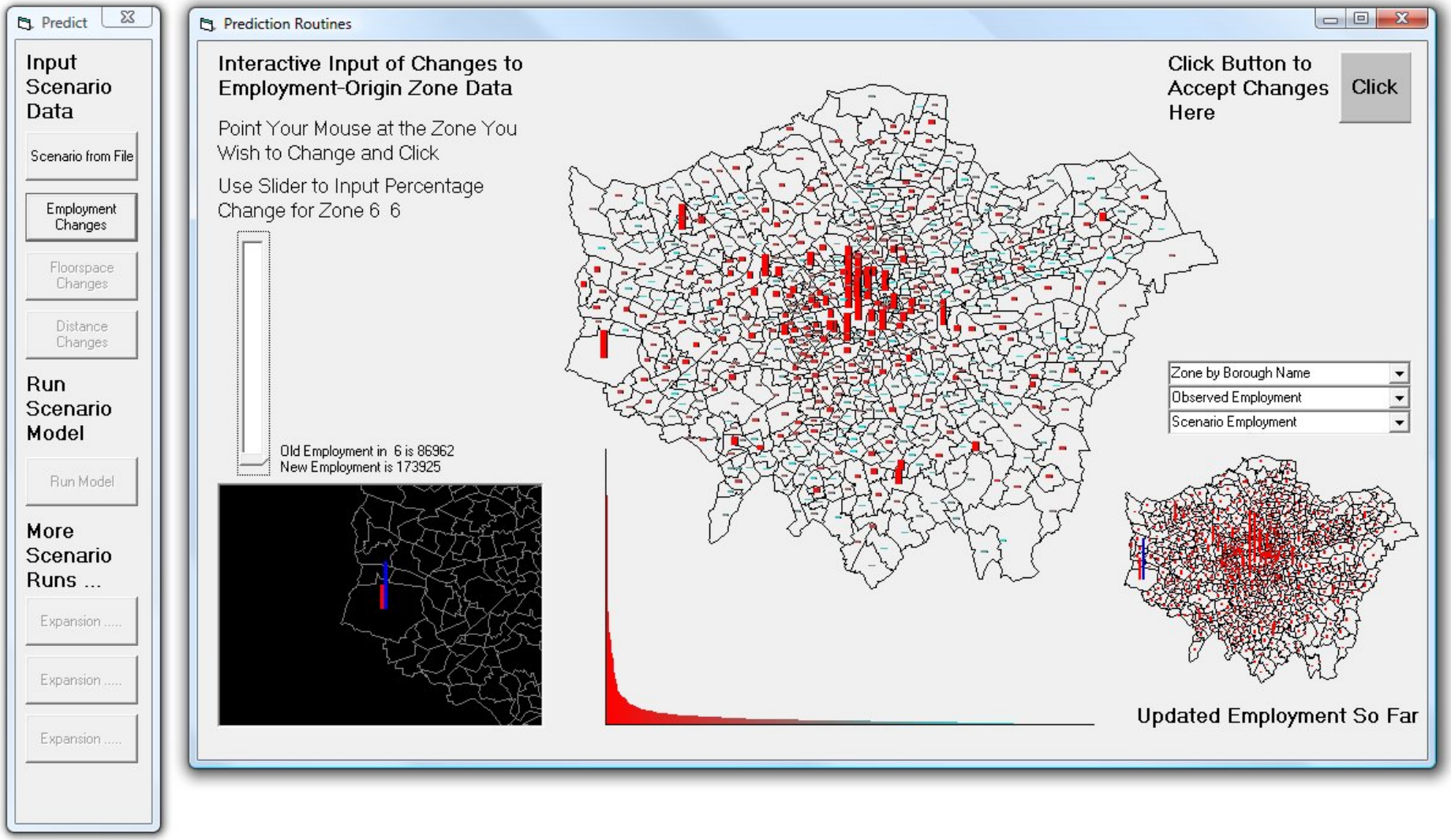
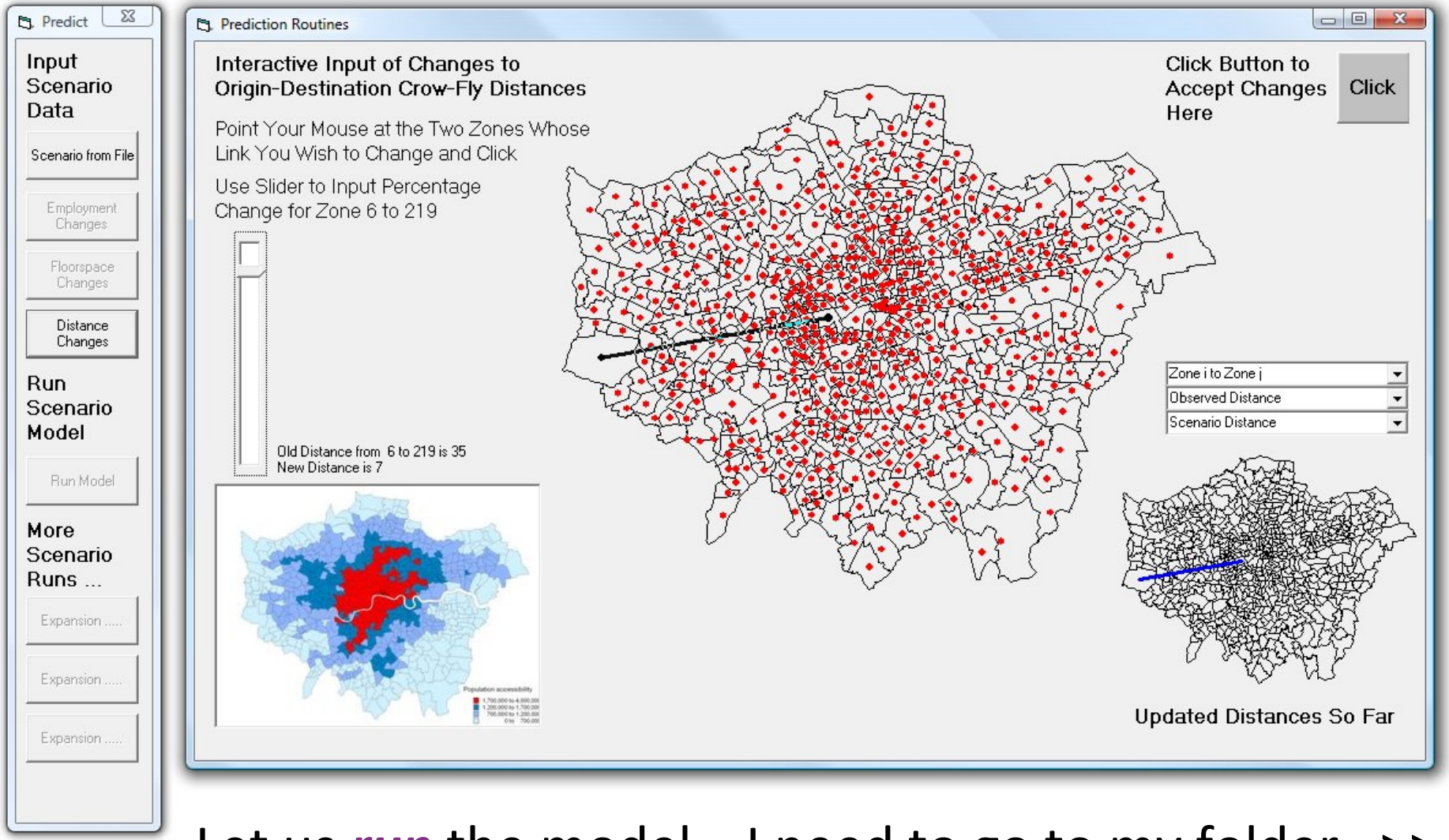
(Form6.frm)
(Form7.frm)
(Form8.frm)
(Form9.frm)
(Module1.bas)

start

08:59


Predict
Input Scenario Data
Scenario from File
Employment Changes
Floorspace Changes
Distance Changes
Run Scenario Model
Run Model
More Scenario Runs ...
Expansion .....
Expansion .....
Expansion .....
Prediction Routines
Interactive Input of Changes to Employment-Origin Zone Data
Point Your Mouse at the Zone You Wish to Change and Click
Use Slider to Input Percentage Change for Zone 6 6
Old Employment in 6 is 86962
New Employment is 173925
Click Button to Accept Changes Here
Click
Zone by Borough Name
Observed Employment
Scenario Employment
Updated Employment So Far



Let us ***run*** the model… I need to go to my folder…>>

Run

For a movie of all this go to our web site
http://www.casa.ucl.ac.uk/transportmodel/transportmodel.asp

And now a little bit more about the model ……looking at how we intend to extend it

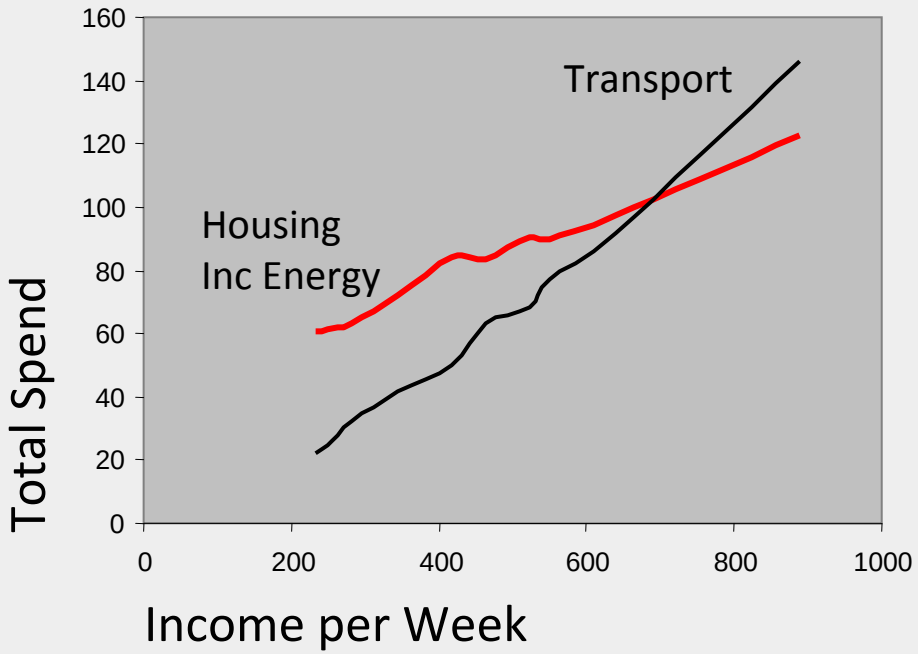
The Economic-Energy Focus

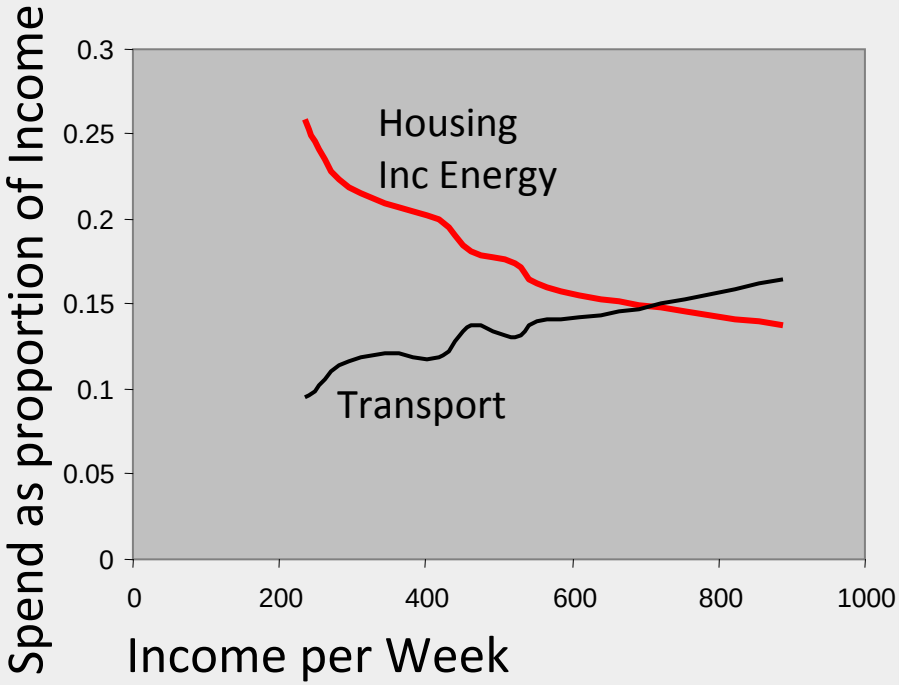
- We have replaced the simple travel cost function with one that relates to wages, travel cost and housing cost
- In essence, we compute the proportion of a wage in any origin (employment zone) which is available for a) travel and b) housing
- Monies for travel are then compared to the actual travel cost on any $i-j$ link and those closest to the cost have a greater probability of determining a trip

- Monies for housing at origin i are then compared to the actual house price at location j and those closest to the housing price have a greater probability of determining the trip
- These are tied together using functions that assume normality around the critical costs. If available monies for travel cost, say, $w(c)_i$, are compared to the travel cost on any link, say c_{ij}^k then the partial probability ρ_{ij}^k of making a trip is computed as $\rho_{ij}^k \sim f(|\, w(c)_i - c_{ij}^k \,|)$
- The same is for housing monies and house prices.

Transport & Housing Costs from the '09 Spending Survey

First let us look at these Costs





Second let us look at the algebraic formulation

The model is as follows

$$T_{ij}^{k} = A_i O_i \exp(-\lambda^{k} \mid c(w)_i - c_{ij}^{k} \mid) \exp(-\beta \mid p(w)_i - p_j \mid)$$

$$D_j = \sum_{ik} T_{ij}^{k}$$

Subject to the following cost constraints

$$\sum_{jk} T_{ij}^{k} = O_i$$

$$\sum_{ij} T_{ij}^{k} \mid c(w)_i - c_{ij}^{k} \mid = C(W)^{k}$$

$$\sum_{ij} T_{ij}^{k} \mid p(w)_i - p_j \mid = P(W)$$

Note that we are not using a destination size effect

- Now we have house price data and we have income data at the destination zone which is y_j per head
- To get wage data, we simply take the trip matrix and apply the income / head for each j and work out the following flows which we sum over destination zones to get the income flowing into each origin zone.

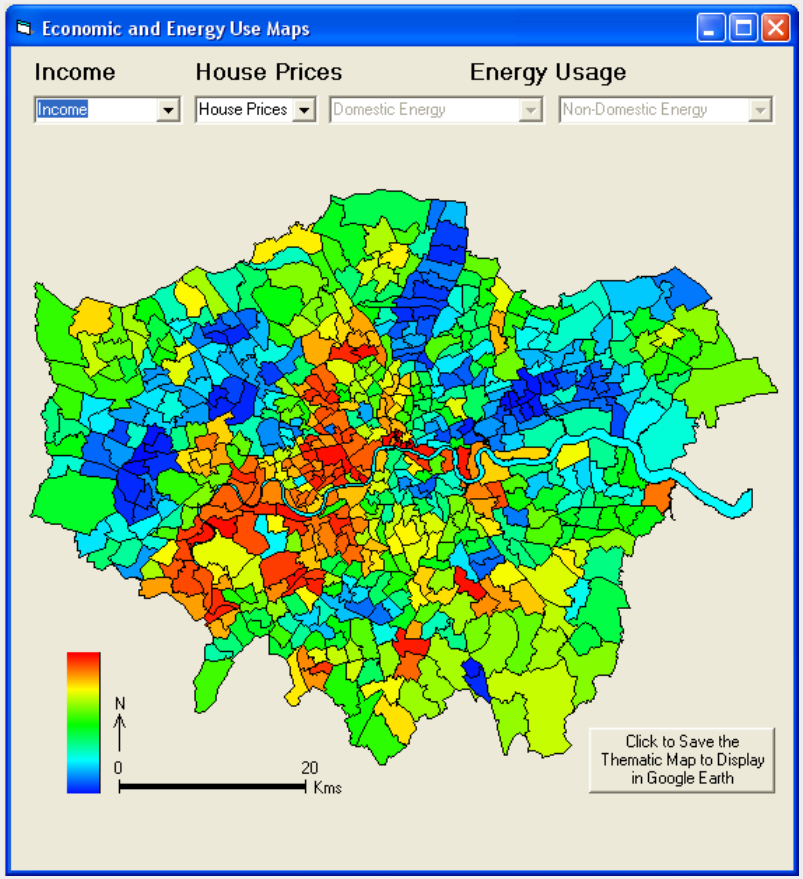
$$T_{ij} y_j = money\ \ flow$$

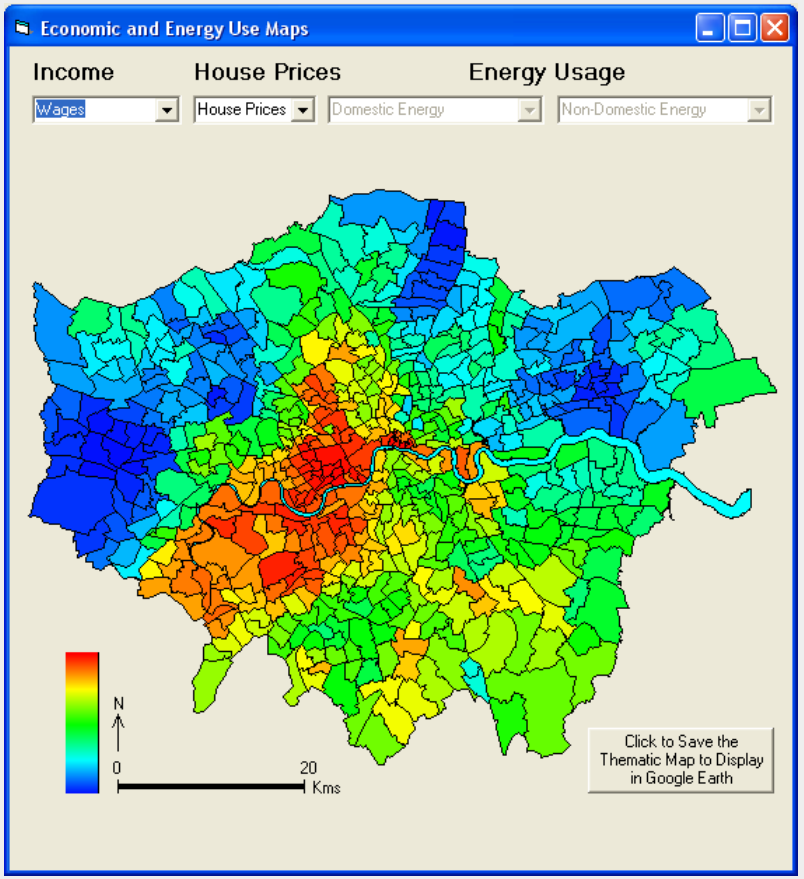
$$\sum_j T_{ij} y_j = W_i \quad \text{and}$$

$$\sum_i T_{ij} y_j = D_j y_j = Y_j$$

$$\sum_i W_i = \sum_j Y_j = M$$

- I will now show what happens when we do this to the data

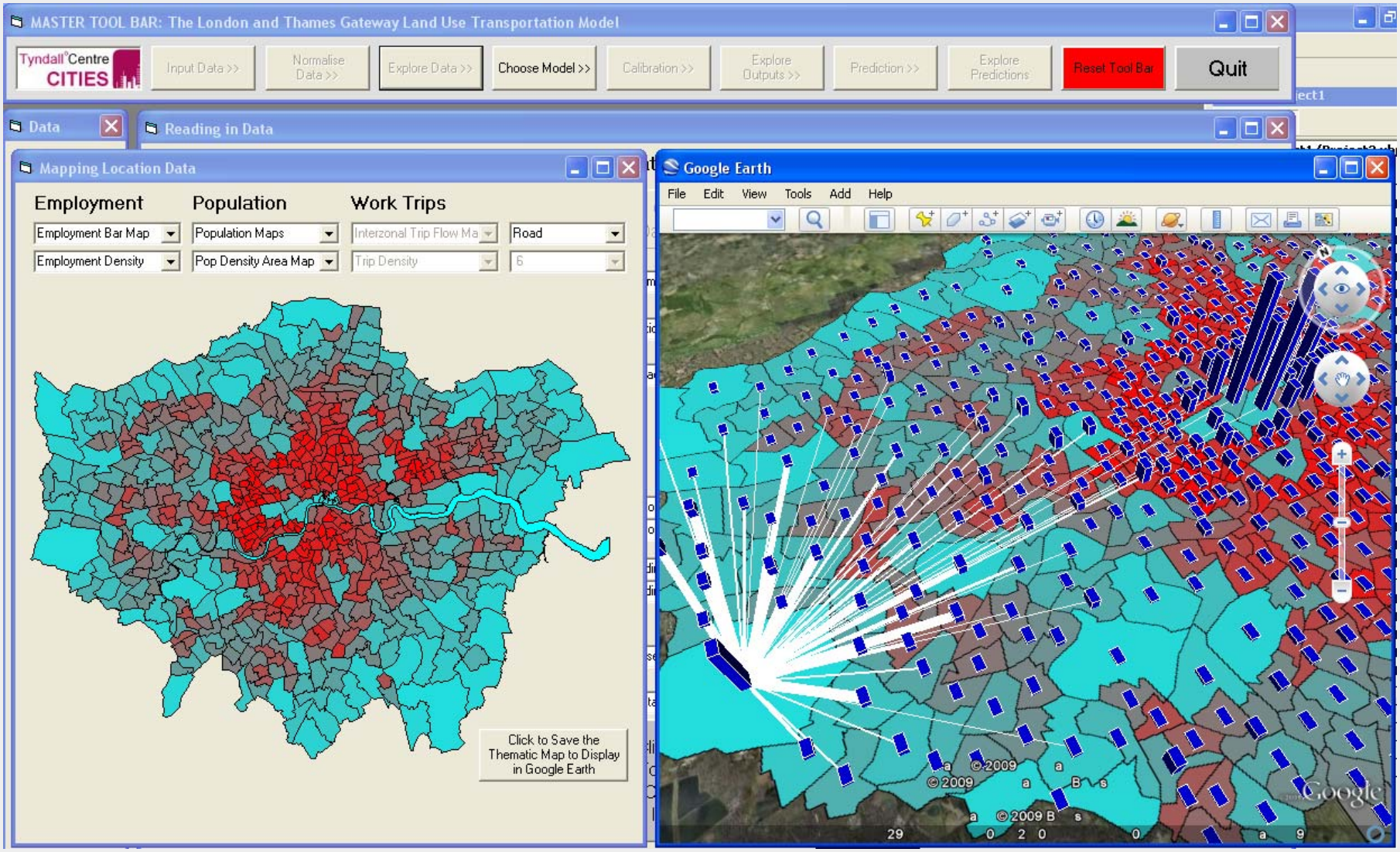




Exploring the Data/Calibrations/Predictions: On-the-Fly Desktop and Web Visualisation

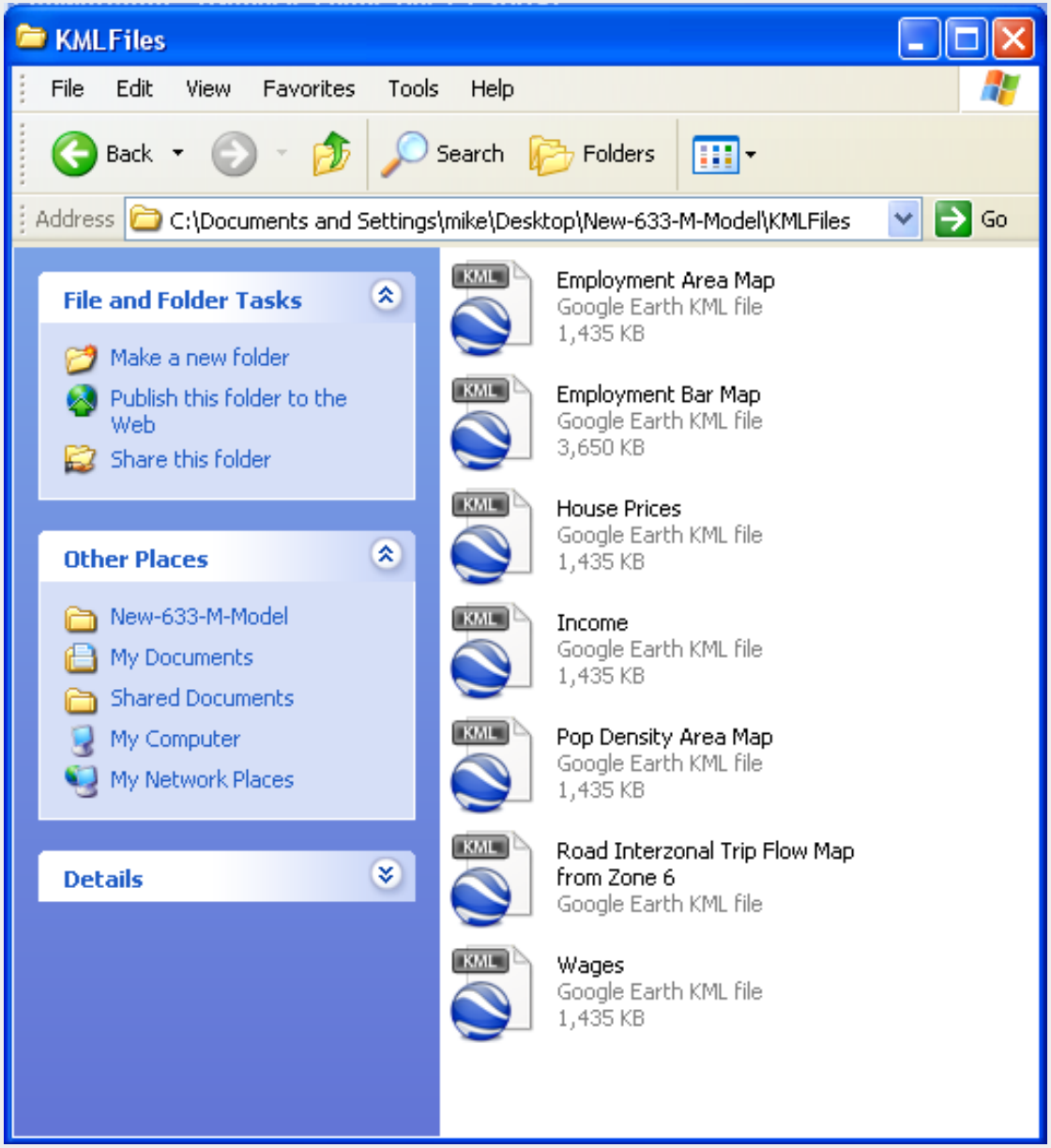
- Currently we do not have good zoom, pan, overlay facilities in the model due to difficulties of such programming in VB (by me that is) – I suspect these could be developed if I had the time !
- But we also need to share the data and the predictions and a quick possibility is to use a non-proprietary open map visualisation system to link on the fly to the model: this should be web-based

- The best way forward at present is to generate KML files in the program and then feed them to *Google Earth* where we have overlay, 3D, and external data facilities. You have seen this.
- In this way, we can extend massively our ability to visualise as well as providing a storage facility for the model input and output data
- What is impressive about this is that the speed of doing all this is not slower than the interactive program in VB – it is extremely fast and highly interactive.


MASTER TOOL BAR: The London and Thames Gateway Land Use Transportation Model
Tyndall Centre CITIES
Input Data >>
Normalise Data >>
Explore Data >>
Choose Model >>
Calibration >>
Explore Outputs >>
Prediction >>
Explore Predictions
Reset Tool Bar
Quit
Data
Reading in Data
Mapping Location Data
Employment
Population
Work Trips
Employment Bar Map
Employment Density
Population Maps
Pop Density Area Map
Interzonal Trip Flow Ma
Trip Density
Road
6
Click to Save the Thematic Map to Display in Google Earth
Google Earth
File Edit View Tools Add Help
©2009
©2009 B
Google

Google Earth/MapTube as London Data Bases

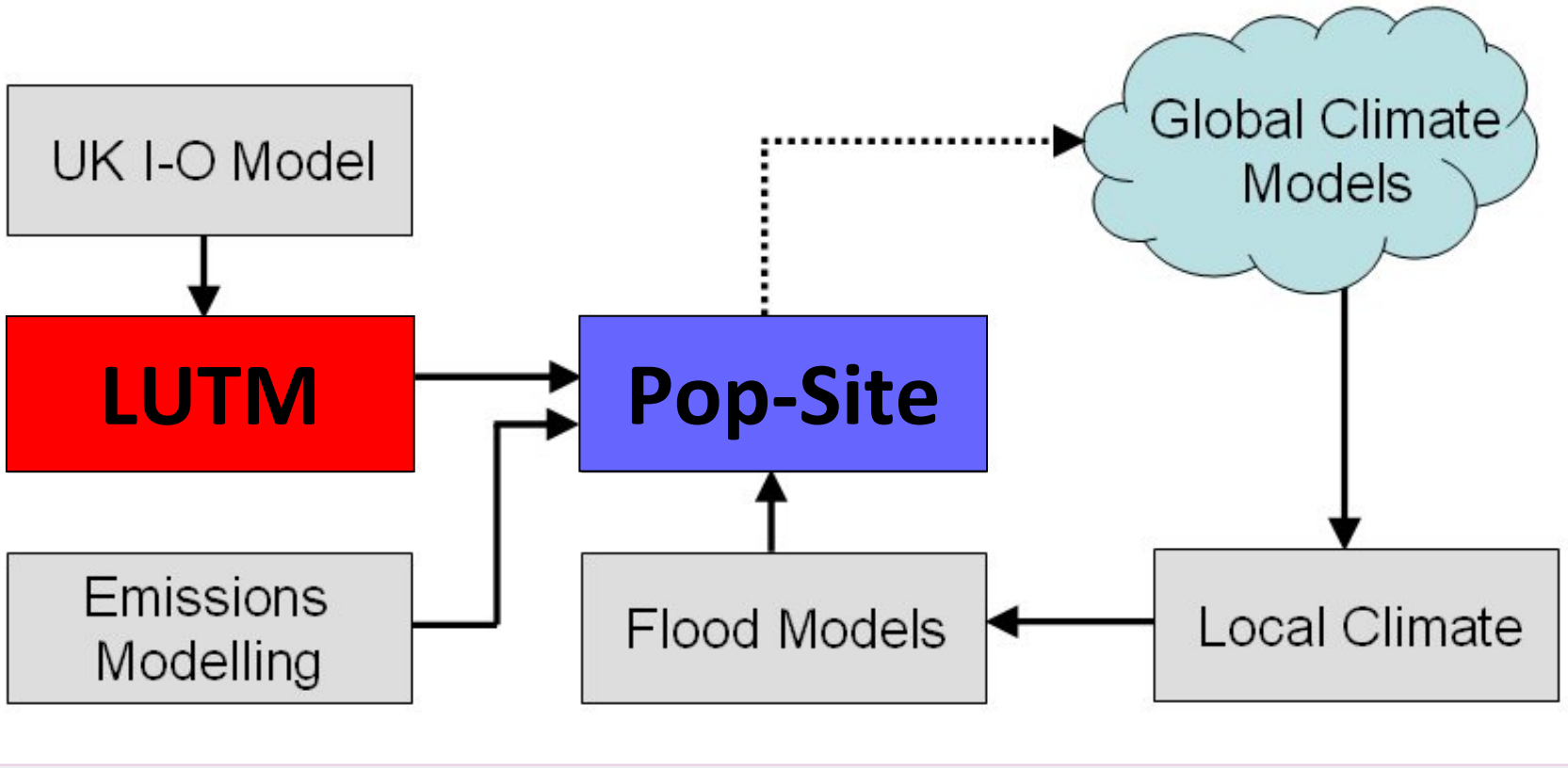
- What is nice about this is the generation of a decent file format KML which we can use in other software – so all the input and output data as KML files can be passed to GIS and so on. See next screen ……
- MapTube of course is one of our main aims here, eventually
- I would like to use external software too for the editing of files for scenario generation but this is uncertain and perhaps unlikely


KMLFiles
File Edit View Favorites Tools Help
Back Search Folders
Address C:\Documents and Settings\mike\Desktop\New-633-M-Model\KMLFiles
Go
File and Folder Tasks
Make a new folder
Publish this folder to the Web
Share this folder
Other Places
New-633-M-Model
My Documents
Shared Documents
My Computer
My Network Places
Details
Employment Area Map
Google Earth KML file
1,435 KB
Employment Bar Map
Google Earth KML file
3,650 KB
House Prices
Google Earth KML file
1,435 KB
Income
Google Earth KML file
1,435 KB
Pop Density Area Map
Google Earth KML file
1,435 KB
Road Interzonal Trip Flow Map from Zone 6
Google Earth KML file
Wages
Google Earth KML file
1,435 KB

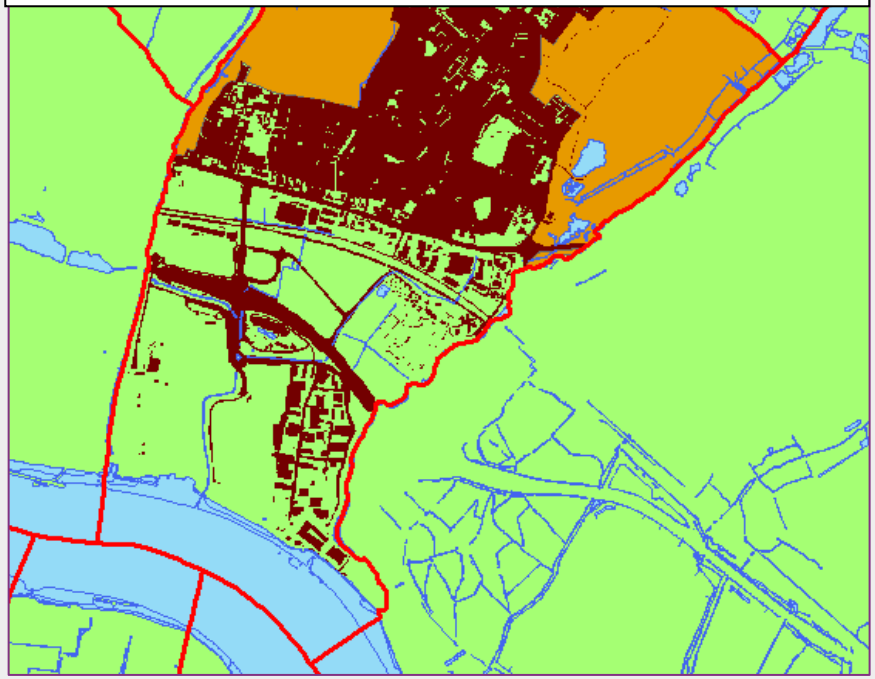
I have said nothing at all about how this model is embedded in the integrated assessment – the string of models that are used to scale national regional forecasts to very small scale. I cannot show you all these models but let me just talk briefly about the next stage down – how we go from 633 zones in London to 50 metre grid squares and this sort of hooks up to another style of modelling

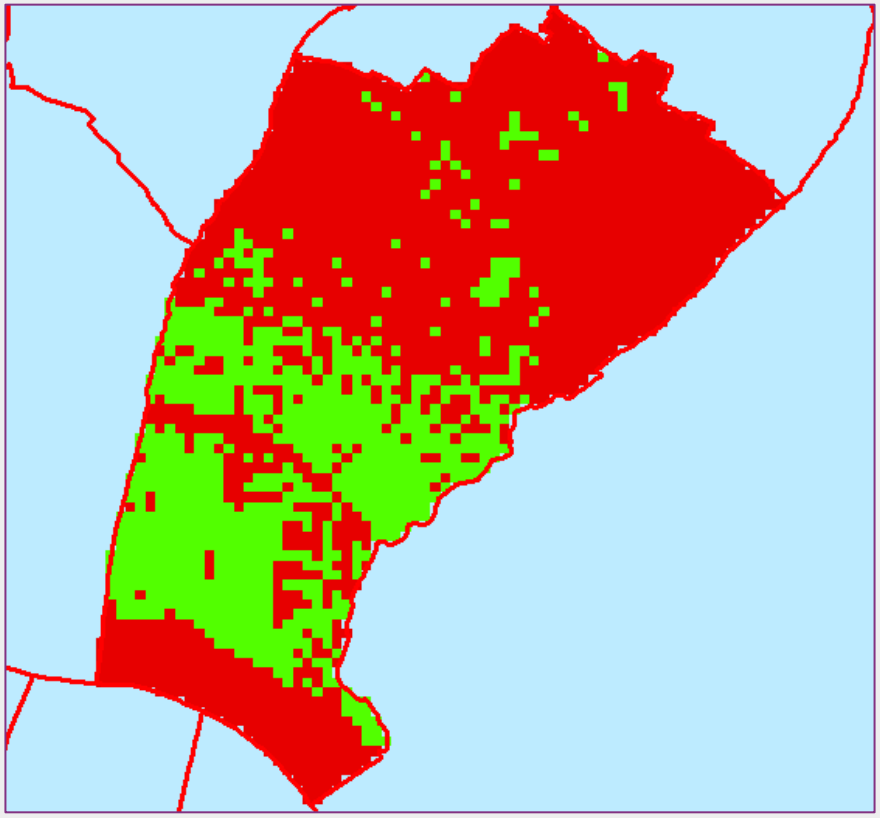
In GIS …..

Here is the integrated assessment block diagram again


UK I-O Model
LUTM
Emissions Modelling
Pop-Site
Flood Models
Global Climate Models
Local Climate

The local development model
GIS layers at 50 metre resolution

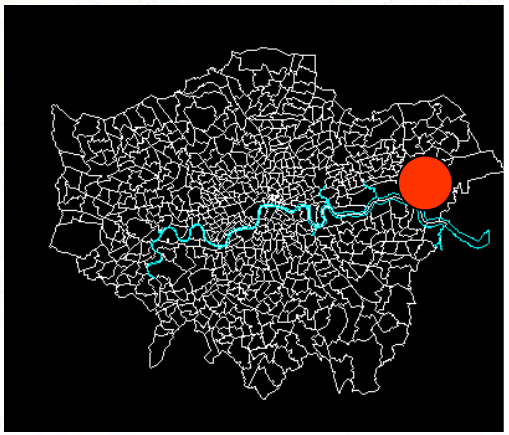


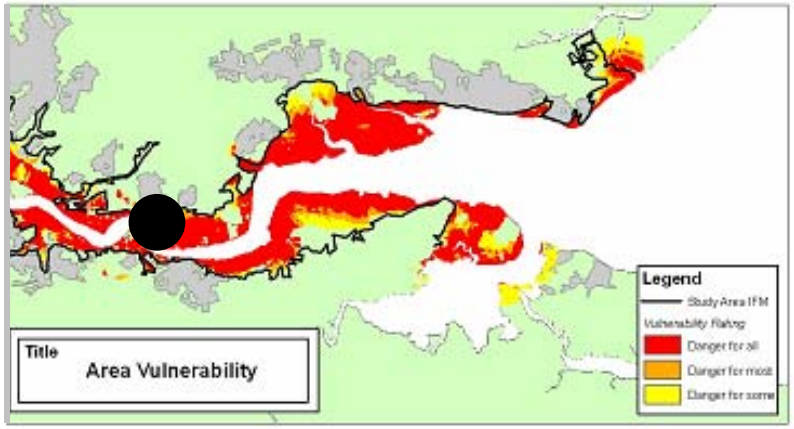


Current Water

Currently Developed

Planning Constrained Land





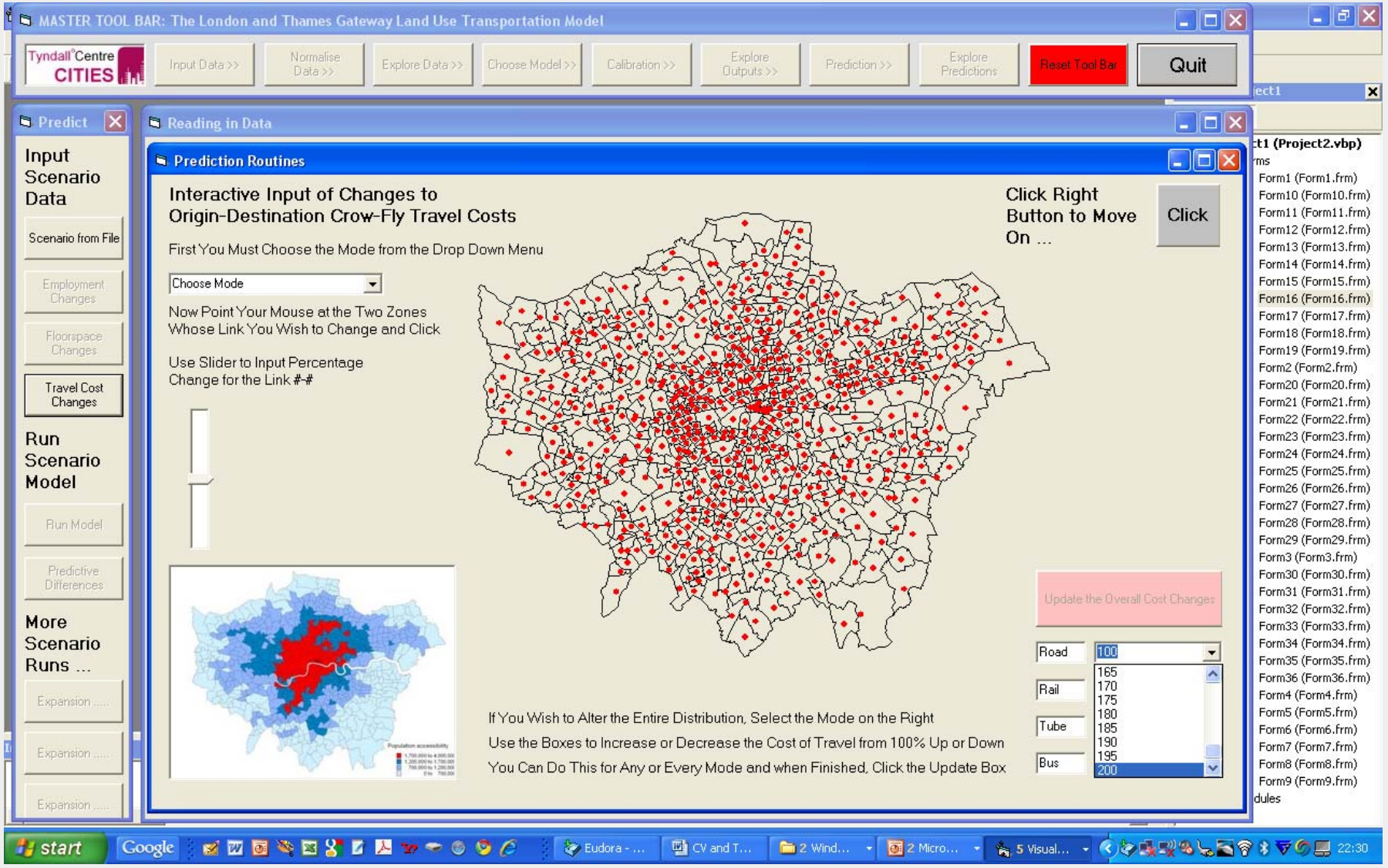
Energy Changes: Rising Costs of Transport

I now want now to show you how we are using the model to handle energy costs in terms of rising costs of transport

What we can do is increase the cost of petrol for road users relative to other modes and see what the effect is

If we double the cost of petrol we then can see how users shift mode of travel and also how location of the population changes

We will show some screen shots of the model doing this


MASTER TOOL BAR: The London and Thames Gateway Land Use Transportation Model
Tyndall Centre CITIES
Input Data >>
Normalise Data >>
Explore Data >>
Choose Model >>
Calibration >>
Explore Outputs >>
Prediction >>
Explore Predictions
Reset Tool Bar
Quit
Predict
Input Scenario Data
Scenario from File
Employment Changes
Floorspace Changes
Travel Cost Changes
Run Scenario Model
Run Model
Predictive Differences
More Scenario Runs ...
Expansion .....
Expansion .....
Expansion .....
Reading in Data
Prediction Routines
Interactive Input of Changes to Origin-Destination Crow-Fly Travel Costs
First You Must Choose the Mode from the Drop Down Menu
Choose Mode
Now Point Your Mouse at the Two Zones Whose Link You Wish to Change and Click
Use Slider to Input Percentage Change for the Link #-#
Click Right Button to Move On ...
Click
Update the Overall Cost Changes
Road
Rail
Tube
Bus
100
165
170
175
180
185
190
195
200
If You Wish to Alter the Entire Distribution, Select the Mode on the Right
Use the Boxes to Increase or Decrease the Cost of Travel from 100% Up or Down
You Can Do This for Any or Every Mode and when Finished, Click the Update Box
Project1
Project1 (Project2.vbp)
Forms
Form1 (Form1.frm)
Form10 (Form10.frm)
Form11 (Form11.frm)
Form12 (Form12.frm)
Form13 (Form13.frm)
Form14 (Form14.frm)
Form15 (Form15.frm)
Form16 (Form16.frm)
Form17 (Form17.frm)
Form18 (Form18.frm)
Form19 (Form19.frm)
Form2 (Form2.frm)
Form20 (Form20.frm)
Form21 (Form21.frm)
Form22 (Form22.frm)
Form23 (Form23.frm)
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Form36 (Form36.frm)
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Form5 (Form5.frm)
Form6 (Form6.frm)
Form7 (Form7.frm)
Form8 (Form8.frm)
Form9 (Form9.frm)
Modules
start
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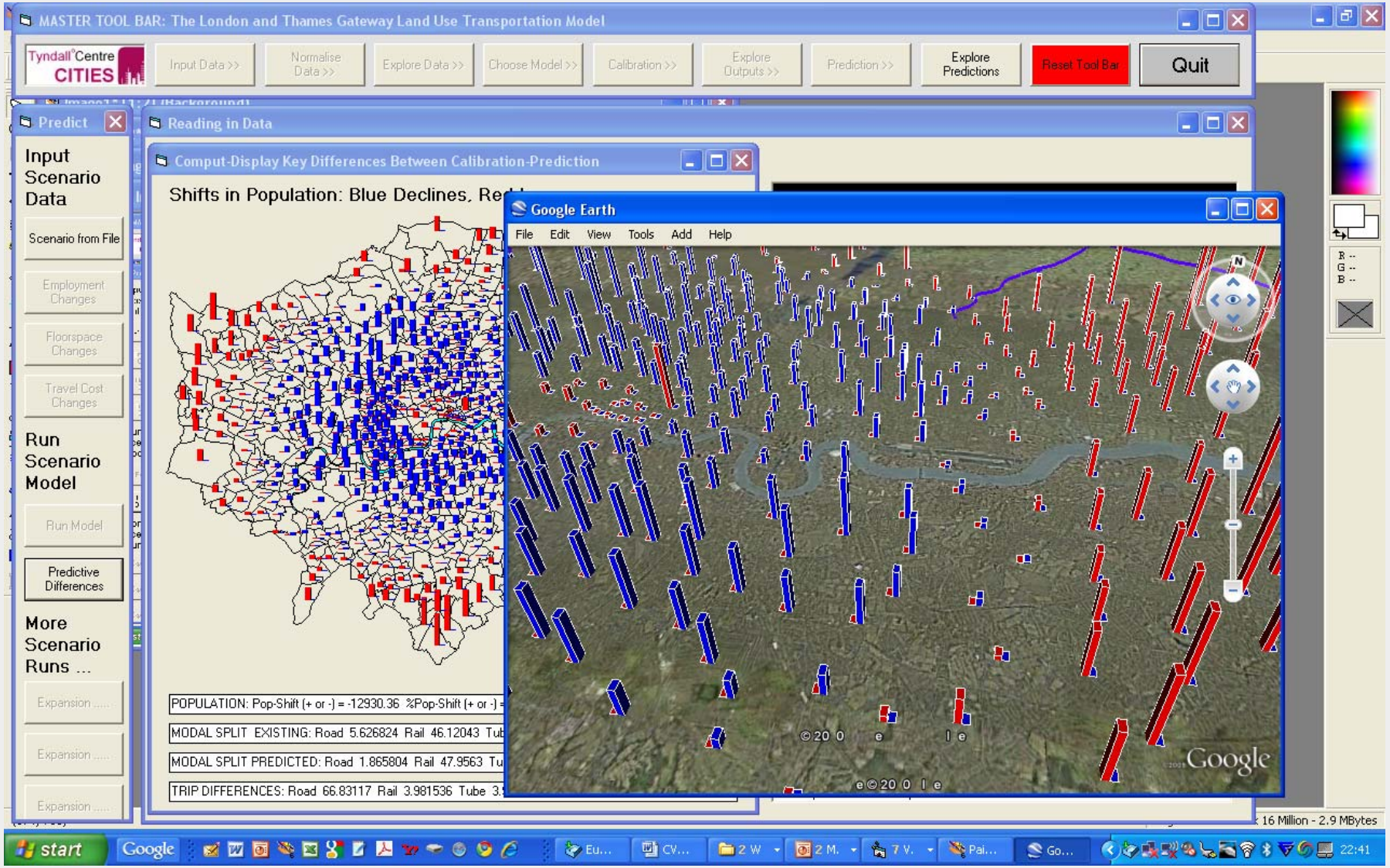
Eudora - ...
CV and T...
2 Wind...
2 Micro...
5 Visual...
22:30


MASTER TOOL BAR: The London and Thames Gateway Land Use Transportation Model
Tyndall Centre CITIES
Input Data >>
Normalise Data >>
Explore Data >>
Choose Model >>
Calibration >>
Explore Outputs >>
Prediction >>
Explore Predictions
Reset Tool Bar
Quit
Predict
Input Scenario Data
Scenario from File
Employment Changes
Floorspace Changes
Travel Cost Changes
Run Scenario Model
Run Model
Predictive Differences
More Scenario Runs ...
Expansion .....
Expansion .....
Expansion .....
Reading in Data
Comput-Display Key Differences Between Calibration-Prediction
Shifts in Population: Blue Declines, Red
POPULATION: Pop-Shift (+ or -) = -12930.36 %Pop-Shift (+ or -)
MODAL SPLIT EXISTING: Road 5.626824 Rail 46.12043
MODAL SPLIT PREDICTED: Road 1.865804 Rail 47.9563
TRIP DIFFERENCES: Road 66.83117 Rail 3.981536 Tube
Google Earth
File Edit View Tools Add Help
Google
16 Million - 2.9 MBytes
start
Google
22:41

Iconic Models: Visualising City Form

Using entirely different sets of skills and with many different applications in mind, we have built a large physical model of the form of Greater London

This has 3.2m buildings BLOCKS within it – it is constructed in Arc-GIS, ported back and forth to 3D Studio max and much other software.

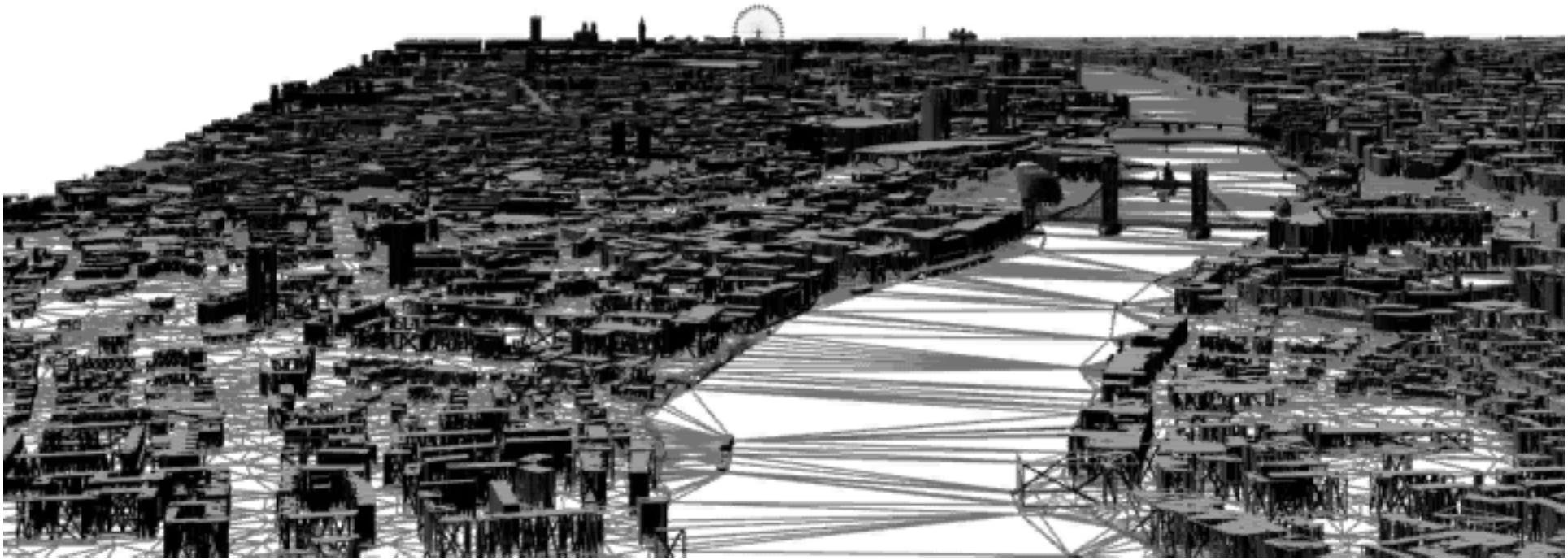
We are using the buildings to tag anything we can get which is geocoded at building level so we can visualise the data in 3D and fly through it

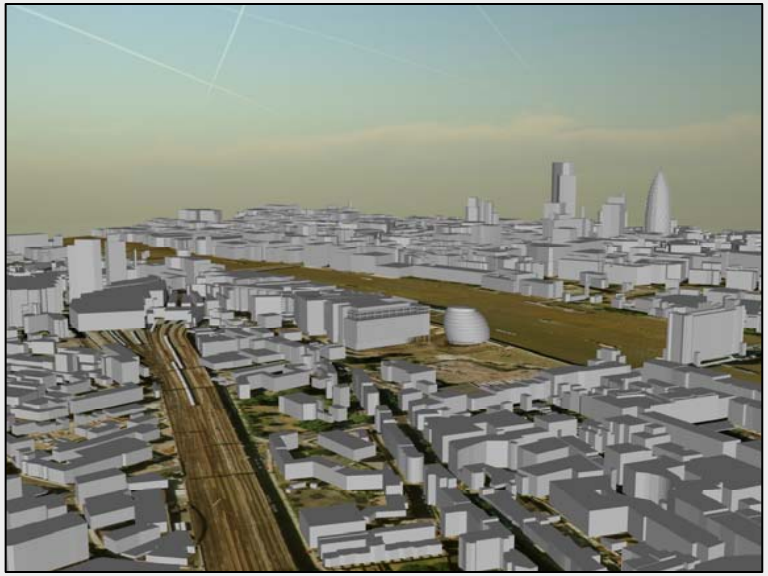
Typical applications are traditional visualisation of population, class, demography, employment but this time not as thematic maps but as building blocks

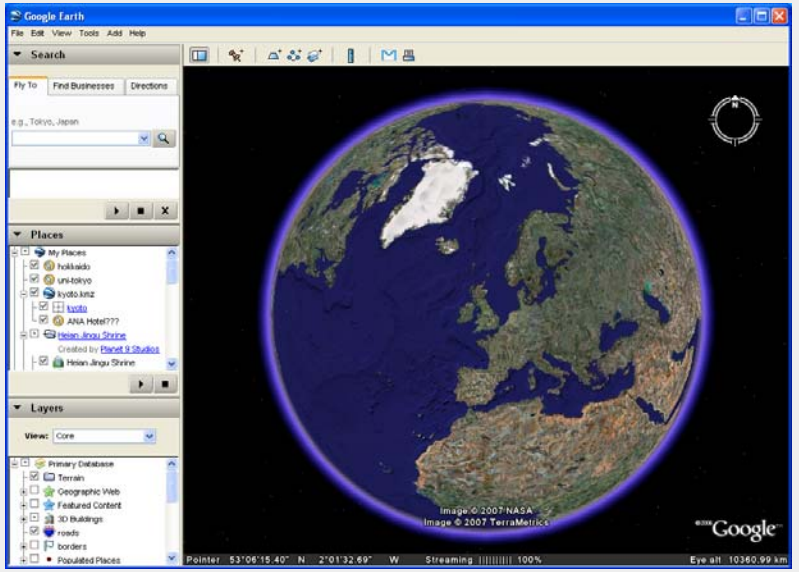
But we also can add different physical layers such as pollution, crime, sea level rise and so on – anything

The model is built from the digital map base provided by our National Mapping Agency – Ordnance Survey and then blocks are extruded from LiDAR data.

We have also explored the allometry and fractal geometry of the building blocks using Geoff West types of scaling. Let me show the model first



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Search
Fly To
Find Businesses
Directions
Places
Layers
Image © 2007 NASA
Image © 2007 TerraMetrics
Google

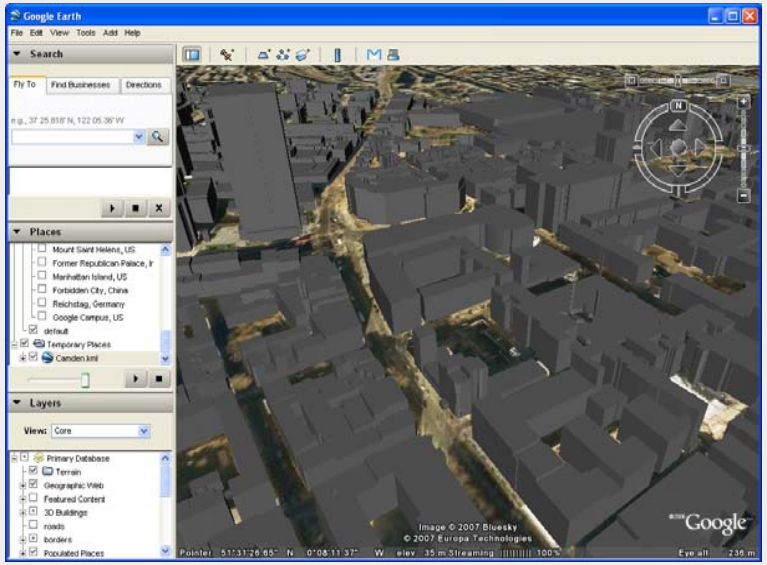
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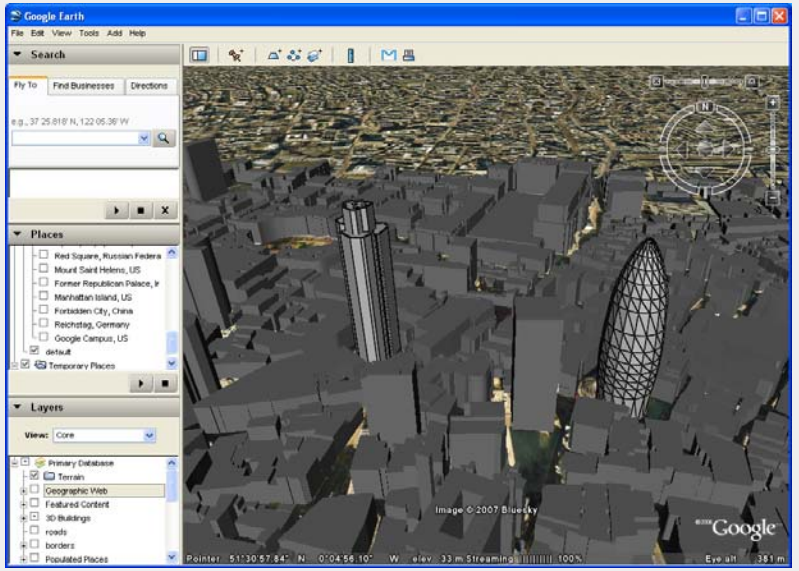
Image © 2007 Bluesky
© 2007 Europa Technologies
Google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Search
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Layers
Image © 2007 Bluesky
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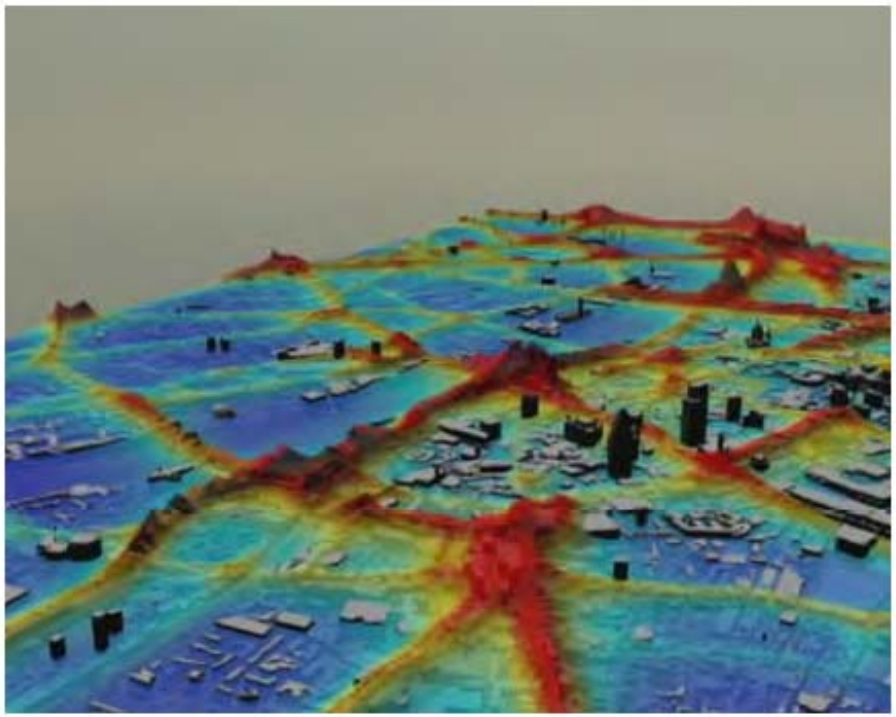
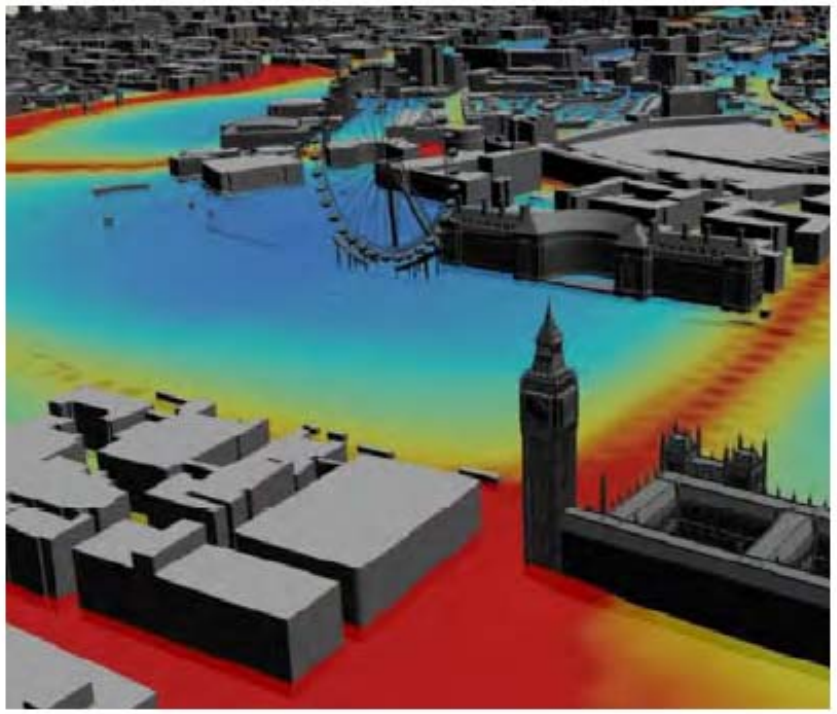
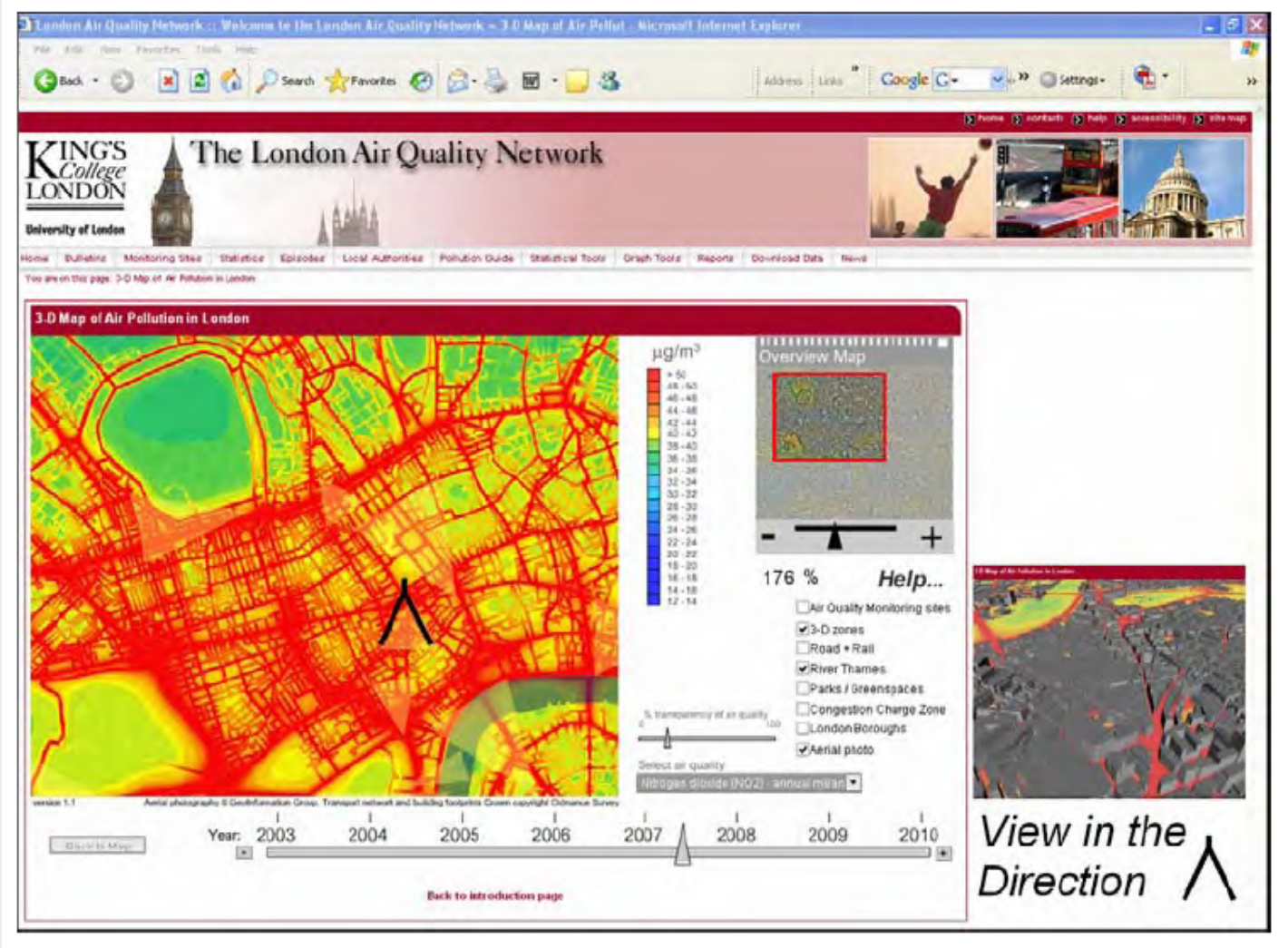
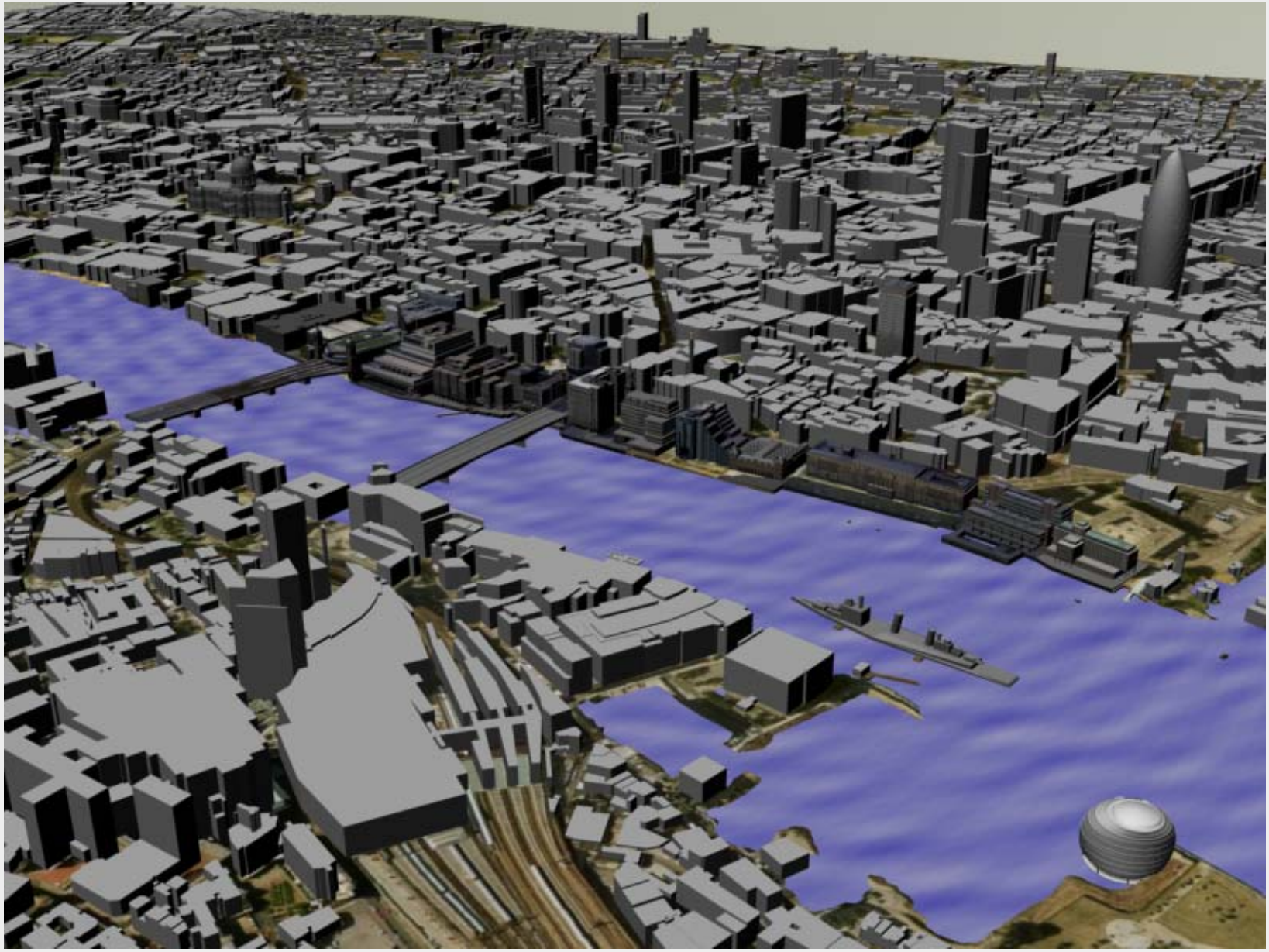
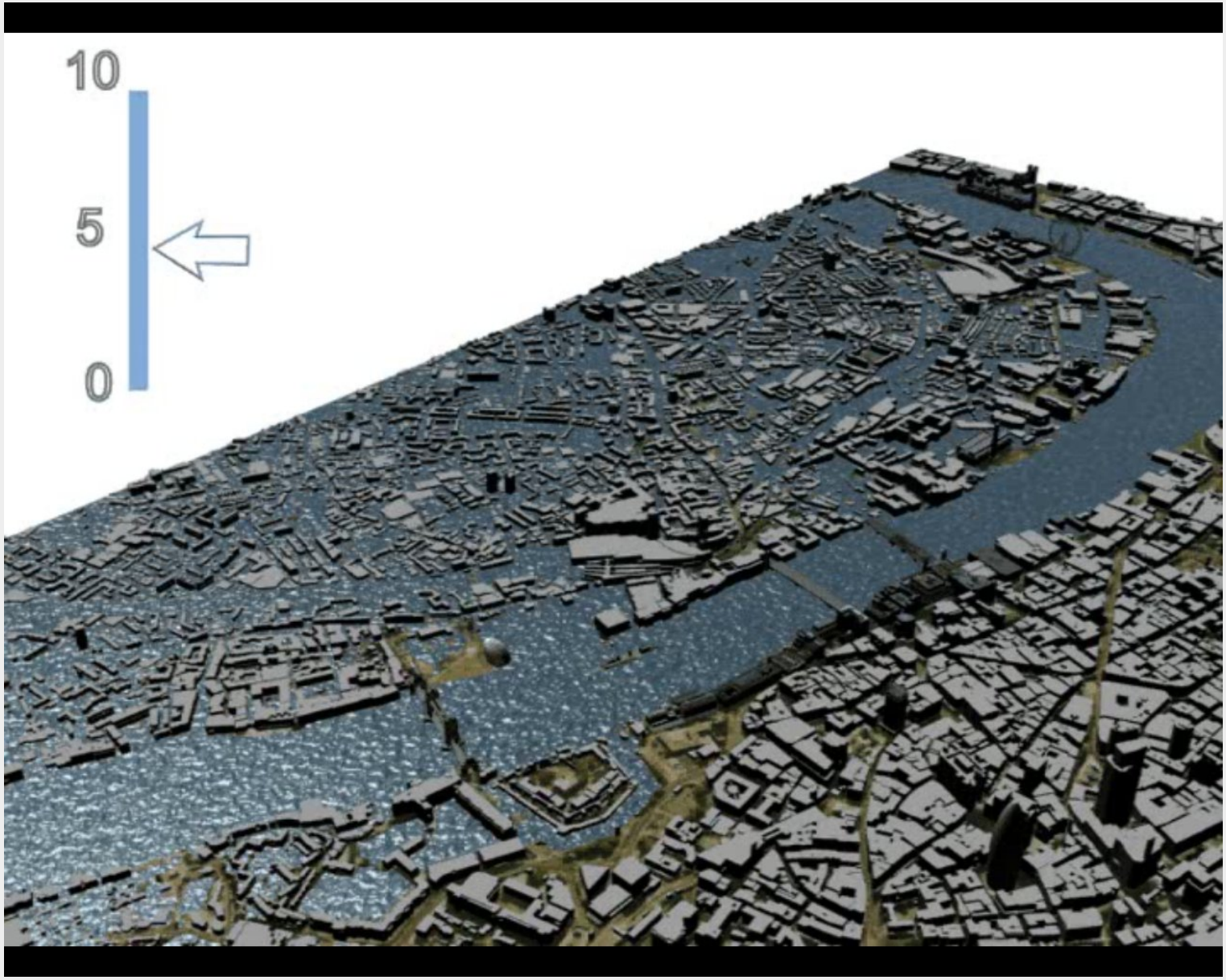






http://www.londonair.org.uk/

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- Blending and Integrating Urban Models: Unanticipated Consequences

I want to finish off by making the point both verbally and visually that we stand at a threshold in beginning to integrate different conceptions, theories if you like, that enable us to grapple with the plurality of viewpoints that are represented when we look at urban problems

We can clearly integrate different types of models through visual interfaces

But the challenge is very much to integrate different kinds of theoretical understanding

This is difficult enough with models at different scales, eg LUTI, agent-based, CA models and so on

But when we begin to add more partial approaches ….

In terms of the move from socio-economic to physical then the way of doing this is clear but the focus changes as we turn activity into real objects, as we turn trips into traffic into cars and trains and so on

Currently all we have are ways of seeing different models side by side through visualisation but this is new enough – if I have time, let me show you…..

If there is time,
I will answer any

Questions

www.casa.ucl.ac.uk