Impacts of climate change on heating and cooling: coupling TIAM-WORLD with the climate model PLASIM-ENTS

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ERMITAGE

Objective
➢ To link together forecast models to assess too often neglected interactions between energy, agriculture, groundwater, energy, economy and climate.

Why does it matter?
➢ Large variations of impacts by region and sector.
➢ Decision-makers must address possible conflicts: food, water, energy, economic growth.
➢ Models and researchers use different languages.

EU contribution (FP7): 3.4 M€
Duration: 36 months (2011-2013)
Coordinator: The Open University (UK)
8 partners in UK, CH, ES, DE
7 models
http://ermitage.cs.man.ac.uk
http://climascope.tyndall.ac.uk
Impacts of temperature change on heating and cooling services

Double objective

• Assess the impacts of CC on heating/cooling services and consequences on the energy system (one-way linkage)

• Assess possible feedback on the climate due to changes in the energy system (two-way linkage)

Consider regional and seasonal temperature changes, as provided by PLASIM-ENTS, in the computation of the heating and cooling services of TIAM-World

Current version of PLASIM-ENTS

PLASIM-ENTS

Statistical emulation

Spatial resolution: T21 (=5°)
Coupling TIAM-WORLD/PLASIM-ENTSem

1) Review of cooling service demands to take into account climate (fixed conditions), saturation and affordability of air conditioning to households, itself depending on incomes

2) Adjustments of cooling and heating service demands according to future CDD and HDD

\[
HeatingDemandAdjusted_{t} = \left( \frac{annual\ HDD_{t}}{annual\ HDD_{2010}} \right) \times HeatingDemand_{t}
\]

\[
HeatingDemandAdjusted_{t1} = \left( \frac{annual\ HDD_{t1}}{annual\ HDD_{t1-1}} \right) \times HeatingDemand_{t1-1}
\]
**Coupling TIAM-WORLD/PLASIM-ENTSem**

![Diagram showing coupling process]

- **TIAM-WORLD**
  - Regional and seasonal heating and cooling services
  - Seasonal evapotranspiration and precipitations (hydropower analysis)

- **PLASIM-ENTSem**
  - Computation and regional mapping of seasonal HDD and CDD (Ref 18°C)
  - Computation of regional and seasonal heating and cooling services

- **GHG concentrations**
  - Population
  - Regions of TIAM-WORLD

**Convergence : overview of the algorithm**

**Step 1.** TIAM-WORLD runs with a global temperature target in 2100.

**Step 2.** Transform TIAM-WORLD outputs into PLASIM-ENTSem inputs (computation of CO2eq)

**Step 3.** PLASIM-ENTSem runs using TIAM-WORLD transformed output

**Step 4.** Transform Temperature and Variability from PLASIM-ENTSem to HDD/CCC and aggregate HDD/CDD to TIAM-WORLD regions

**Step 5.** Transform seasonal and regional Heating/Cooling demands (demands + seasonal share) in TIAM-WORLD

**Step 6.** Check convergence temperature from PLASIM-ENTSem and target
  - If close (0.001 or 0.01), end.
  - If not, adjust temperature, go to 1

\[ T_{TIAM}^{n+1} = T_{TIAM}^n + \alpha \times (T_{max[\text{target}]} - T_{PLASIM}^n) \]
**Experiment 1: Speed of convergence**

Series of scenarios

- 1 reference case without climate change: changes in heating and cooling are driven only by socio-economic drivers
- 20 different future radiative forcing trajectories (=> from 1.6°C to 8°C in 2100), which could be interpreted as due to uncertain contribution by aerosols, CH4 release from permafrost/oceans, etc.

**Main result**

- Negligible feedback on the climate
- Visible impact of CC on heating and cooling

**Experiment 2: Impacts on the energy system**

Series of scenarios

- 1 reference case without climate change: changes in heating and cooling are driven only by socio-economic drivers
- 20 different future radiative forcing trajectories (=> from 1.6°C to 8°C in 2100), which could be interpreted as due to uncertain contribution by aerosols, CH4 release from permafrost/oceans, etc.

**Main result**

- Negligible feedback on the climate
- Visible impact of CC on heating and cooling
a) Heating and cooling are less than 10% of total energy consumed/total emissions

![Graph showing Share of heating and cooling energy consumption in total final energy consumption when climate change impacts are considered.](image)

b) Balanced cooling/heating impacts on emissions: less emissions at residential/commercial level, more at power level

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### Heating and Cooling Degree Days

**Pop-weighted CDD from 2005 to 2090**
(long-term global average temperature increase of 3.3 °C)

**Pop-weighted HDD from 2005 to 2090**
(long-term global average temperature increase of 3.3 °C)
Energy consumption for heating and cooling

Insights from the Reference Case (long-term temperature increase of 3.3°C)

<table>
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<tr>
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<th>NoCC</th>
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<td>33</td>
<td>23</td>
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</tr>
</tbody>
</table>

Average long-term temperature increase is 3.3°C over pre-industrial

NoCC represents energy consumption without considering climate change impacts on heating and cooling.

CC represents energy consumption when considering climate change impacts on heating and cooling.

Per fuel, end of the century

Insights from the Reference Case (long-term temperature increase of 3.3°C)

Final Energy Consumption - Commercial & Residential heating - World

Final Energy Consumption (electricity) - Commercial & Residential cooling - World
Insights from the Reference Case
(long-term temperature increase of 3.3°C)

Regional perspective

Energy consumption for residential cooling and heating - India
(average long-term temperature increase of 3.3°C over pre-industrial)

- Heating
- Cooling

Regional perspective

Energy consumption for residential cooling and heating - Russia
(average long-term temperature increase of 3.3°C over pre-industrial)
Electricity production

Insights from the Reference Case (long-term temperature increase of 3.3°C)

Electricity production at World level

Regional perspective

Insights from the Reference Case (long-term temperature increase of 3.3°C)
In summary

• Coupled TIAM-WORLD / PLASIM-ENTS
  • Operational and efficient
  • Regional and seasonal climate information
  • Improved Integrated Assessment Models

• Consideration of impacts of CC on heating/cooling dynamics is important
  • Not for global climate feedback
  • Yes for energy planning and climate policies at local and sector levels: non-small local energy impacts, pressure on electricity supply, transfer of emissions from residential/commercial sectors to power sector

Next steps

Bioenergy: Coupling TIAM-WORLD/MAgPIE

Hydro: Coupling TIAM-WORLD / PLASIM-ENTS: precipitation and evapotranspiration

PLASIM-ENTS: Detailed CO2 cycle


More information
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### Annexes

#### Transfer of data TIAM-WORLD/PLASIM-ENTS

<table>
<thead>
<tr>
<th>Data</th>
<th>File</th>
<th>Partial view of the content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature target imposed in TIAM-WORLD (step 1)</td>
<td>TempIncrease_1</td>
<td>Partial view of the content</td>
</tr>
<tr>
<td>CO2-eq concentration from TIAM-WORLD, used to compute the Chebychev coef, inputs of PLASIM-ENTS</td>
<td>C-T_1</td>
<td>(etc. up to 2100)</td>
</tr>
</tbody>
</table>
Transfer of data TIAM-WORLD/PLASIM-ENTS

<table>
<thead>
<tr>
<th>Global temp increase from PLASIM-ENTS (steps 4 and 5)</th>
<th>Global_warming_1</th>
</tr>
</thead>
</table>

| Seasonal and regional HDD and CDD from PLASIM-ENTS, already transformed into TIAM-WORLD's regions (steps 4 and 5) | TIAM_Regions_CDD_1 and TIAM_Regions_HDD_1 |

Coupling TIAM-WORLD/PLASIM-ENTS

![Diagram showing air conditioner saturation vs. cooling degree days and income vs. availability of air conditioning.]
Future version of PLASIM

PLASIM
3D primitive equation
ATMOSPHERE

FIXED thermodynamic SEA ICE
ENTS dynamic VEGETATION

Flux-corrected slab OCEAN

PLASIM
3D primitive equation
ATMOSPHERE

Dynamic-thermodynamic SEA ICE
ENTS dynamic VEGETATION

GOLDSTEIN 3D Frictional geostrophic OCEAN

Current version of PLASIM-ENTS

PLASIM-ENTS

PLASIM
3D primitive equation
ATMOSPHERE

FIXED thermodynamic SEA ICE
ENTS dynamic VEGETATION

Flux-corrected slab OCEAN

Spatial resolution: T21 (≈5°)

Statistical emulation

Simulated ensemble average

Emulated ensemble average

mm/day
CC and hydro potential (preliminary)

TIAM-WORLD

Regional and seasonal heating and cooling services

PLASIM-ENTSem

Seasonal evapotranspiration and precipitations (hydropower analysis)

GHG concentrations

Population

Regions of TIAM

Seasonal local temperatures

Computation and regional mapping of seasonal HDD and CDD (Ref 18°C)

Computation of regional and seasonal heating and cooling services

* Saturation and dissemination factors are considered

Population

Regions of TIAM

Computation and regional mapping of seasonal HDD and CDD (Ref 18°C)

Methodology

Precipitation

Evapotranspiration

Elevation

Run-off

\[ E_i = m_i \cdot g \cdot \Delta h_i \]

For all \( i \)

Where

- \( E_i \): potential energy of run-off water in grid cell \( i \)
- \( m_i \): mass of run-off water in grid cell \( i \)
- \( g \): average gravity acceleration
- \( \Delta h_i \): elevation difference between grid cell \( i \) and lowest neighboring grid cell
Results (preliminary)

Current hydropower potential

- Theoretical hydro potential higher in Asia and Africa compared to literature (areas with high elevation differences => any small changes in run-off may translate in high hydro potential)

Results (preliminary)

Impacts of CC

- Increase of hydropower potential of around 15% in the long-term at the World level
- Regional and seasonal variations (eg. Canada, decrease in summer)
- Increase observed also in Europe, contrary to other sources => under validation

Difference between run-off balance (precipitation – evapotranspiration) between Period 9 and Period 0

Red cells: increase in run-off balance (hydro potential ↑)
Green cells: decrease (hydro potential ↓)