### Dynamic LCA ghgforcing – an open source Python package

**Greg Schivley** 64<sup>th</sup> LCA Discussion Forum March 30, 2017

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### Most LCA studies use GWP for climate impacts



### Emissions happen over time, might be variable



### Biogenic uptake and emissions at different times



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Cherubini, F., Guest, G. & Strømman, A. Application of probablity distributions to the modelleing of biogenic CO2 fluxes in life cycle assessment. *Global Change Biology* **4**, 784–798 (2012).

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# Calculation of radiative forcing

$$RF(t) = RE \int_0^t g(t')y(t-t')dt'$$

- Every emission decays according to a response function
- Mass of a species in the atmosphere is calculated using a convolution of the emission and response functions (above)

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# Introducing ghgforcing

- Open-source Python library
  - github.com/gschivley/ghgforcing
  - -pip install ghgforcing
- Calculates RF, CRF, temperature for CO<sub>2</sub> and CH<sub>4</sub>

**Policy Analys** Review

Identifying/C Reduction S Enhancing life cycle impact assessment from climate science: Review :t Metrics atural Gas

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# ghgforcing basic parameters

- Array of emissions
- Array of time (same length as emissions)
- kind of calculation (RF, CRF, or temp)
- Returns: results on annual basis over length of time array

## A simple example

1 kg generic emission every year for 50 years

```
end_time = 100
tstep = 0.1
time = np.linspace(start=0, stop=end_time, num=int(end_time/tstep))
emission = np.ones_like(time)
emission[500:] = 0
```

#### Make CO<sub>2</sub> 50 kg/yr

```
co2_rf = CO2(emission * 50, time, tstep=0.1, kind='RF')
ch4_rf = CH4(emission, time, tstep=0.1, kind='RF')
plt.plot(co2_rf, label='50kg CO2')
plt.plot(ch4_rf, label='1kg CH4')
```



### Calculate CRF

```
co2_crf = CO2(emission * 50, time, tstep=0.1, kind='CRF')
ch4_crf = CH4(emission, time, tstep=0.1, kind='CRF')
plt.plot(co2_crf, label='50kg CO2')
plt.plot(ch4_crf, label='1kg CH4')
```



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### Or calculate temperature



## Support for irregular timeframes

years = np.array([2000, 2010, 2015, 2020, 2025, 2050])
emissions = np.array([-10, 2, 5, 20, 0, 0])



## Other calculation features

- Methane with or without:
  - Climate-carbon feedbacks
  - Decomposition to  $CO_2$

| cc-feedbacks | $CH_4 \rightarrow CO_2$<br>(fossil $CH_4$ ) | Equivalent<br>100-yr GWP |
|--------------|---|--------------------------|
| ×            | ×   | 28                       |
| ×            | $\checkmark$                                | 30                       |
| $\checkmark$ | ×   | 34                       |
| $\checkmark$ | $\checkmark$                                | 36                       |

- Uncertainty
  - Radiative efficiencies
  - Methane indirect effects
  - Methane lifetime
  - Fraction methane to  $CO_2$
  - Climate-carbon feedbacks
  - CO<sub>2</sub> response function
- Return ± 1-sigma, or full monte carlo results

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### Sample uncertainty



# Caution with pulse emissions!

- ghgforcing was designed for <u>continuous</u> emissions
- 1kg at every timestep over a year is interpreted as 1kg for the year
- Default time-step is 0.01 years
- A pulse in the first step will be 1/tstep too small!

### >Change tstep or multiply a pulse emission by 1/tstep

# easyghg if you don't want to use Python

- Basic excel interface
- Uses ghgforcing
- github.com/gschivley/easyghg
  - Needs to be fixed after recent updates to xlwings
  - Let me know if this is something you'd like to use

| •  |      | □ Б Ю Y び Ŧ В easyghg            |                                  |      |             |              |               |      |         | Q- Search Sheet |         |        |       |                 |       |              |                |        |
|----|------|----------------------------------|----------------------------------|------|-------------|--------------|---------------|------|---------|-----------------|---------|--------|-------|-----------------|-------|--------------|----------------|--------|
|    | Home | Insert Page                      | Layout Formu                     | ulas | Data Rev    | view Viev    | v Devel       | oper |         |                 |         |        |       |                 |       |              |                | 2      |
| B8 | 4    | $\times \checkmark f_x$          |                                  |      |             |              |               |      |         |                 |         |        |       |                 |       |              |                |        |
|    | A    | В                                | С                                | D    | E           | F            | G             | н    | 1       | J               | К       | L      |       | M               | N     | 0            | Р              |        |
| L  |      |                                  |                                  |      |             | Mean Values  |               |      |         |                 |         |        |       | Methane option  | ns:   |              |                |        |
|    | Year | CO <sub>2</sub> Emission (kg/yr) | CH <sub>4</sub> Emission (kg/yr) |      | CO2 forcing | CH4 forcing  | Total Forcing |      |         |                 |         |        |       | Fossil          | True  |              |                |        |
| 8  | 0    | 1                                | 1                                |      | (           | 0 2.1071E-15 | 2.107E-15     |      |         | Calculate       | forcing |        |       | cc-fb           | True  | 1            |                |        |
| 4  | 1    | 1                                | 1                                |      | (           | 0 2.0447E-13 | 2.045E-13     |      |         |                 | _       |        |       |                 |       |              |                | -      |
| 5  | 2    | 1                                | 1                                |      | (           | 0 3.9125E-13 | 3.912E-13     |      |         |                 |         |        |       | MC options:     |       |              |                |        |
| 6  | 3    | 1                                | 1                                |      | (           | 0 5.6378E-13 | 5.638E-13     |      |         |                 |         |        |       | runs            | 1000  |              |                |        |
| 7  | 4    | 1                                | 1                                |      | (           | 0 7.2326E-13 | 7.233E-13     |      |         |                 |         |        |       | random state    | 5     |              |                | -      |
| в  | 5    |                                  | 1                                |      | (           | 0 8.7078E-13 | 8.708E-13     |      |         |                 |         |        |       | full output     | True  | Full output  | will write the | resul  |
| 9  | 6    |                                  | 1                                |      | (           | 0 1.0073E-12 | 1.007E-12     |      |         |                 |         |        |       |                 |       |              |                |        |
| 0  | 7    | ,                                | 1                                |      |             | 0 1.1339E-12 | 1.134E-12     |      |         |                 |         | _      |       | Other options:  |       |              |                | -      |
| 1  |      | 2                                | 1                                |      | (           | 0 1.2512E-12 | 1.251E-12     |      |         |                 |         |        |       | Pulse emissions | False | Select "True | " for more a   | ccurat |
| 2  | 9    |                                  | 1                                |      |             | 0 1.36E-12   | 1.36E-12      |      |         |                 |         |        |       | RE or CRE       | RF    | beleet frac  | lor more de    | Ceard  |
| 3  | 10   |                                  | 1                                |      | (           | 1.461E-12    | 1.461E-12     |      |         |                 |         |        |       |                 |       |              |                | -      |
| 4  | 11   |                                  | 1                                |      |             | 1 5549F-12   | 1 5555-12     |      |         |                 |         |        |       |                 |       |              |                |        |
| 5  | 12   |                                  | 1                                |      |             | 1 6423E-12   | 1 642E-12     |      |         |                 |         | · · ·  |       | <b>F</b>        |       |              |                |        |
| 6  | 12   |                                  | 1                                |      |             | 1 7225E-12   | 1 7245-12     |      |         |                 |         |        | меа   | n Forcing       |       |              |                |        |
| 7  | 14   |                                  | 1                                |      |             | 1.7233E-12   | 1 7995-12     |      | 2.5     | 1e-12           |         | with 1 | l-sig | ma uncerta      | inty  |              |                |        |
| 0  | 14   |                                  | 1                                |      |             | 1.7555E-12   | 1.7550-12     |      |         |                 |         |        |       |                 |       |              |                |        |
| 0  | 10   |                                  | 1                                |      |             | 1.0059E-12   | 1.076-12      |      |         |                 |         |        |       |                 |       |              |                |        |
| 9  | 10   |                                  | 1                                |      |             | 1.9336E-12   | 1.9502-12     |      |         |                 |         |        |       |                 |       |              |                |        |
| 0  | 1/   |                                  | 1                                |      |             | J 1.9974E-12 | 1.997E-12     |      | 20      |                 |         |        |       |                 |       |              |                |        |
| 1  | 10   |                                  | 1                                |      |             | 2.0349E-12   | 2.0556-12     |      | 2.0     |                 |         |        |       |                 |       |              |                |        |
| 2  | 19   |                                  | 1                                |      |             | J 2.1088E-12 | 2.109E-12     |      |         |                 |         |        |       |                 |       |              |                |        |
| 3  | 20   | ·                                | 1                                |      | (           | 0 2.1593E-12 | 2.159E-12     |      |         |                 |         |        |       |                 |       |              |                |        |
| 4  | 21   |                                  |                                  |      | (           | 0 2.103E-12  | 2.103E-12     |      | 15      |                 |         |        |       |                 |       |              |                |        |
| 5  | 22   |                                  |                                  |      | (           | 0 1.9529E-12 | 1.953E-12     |      | 1.0     |                 |         |        |       |                 |       |              |                |        |
| 6  | 23   |                                  |                                  |      | (           | 0 1.8151E-12 | 1.815E-12     |      | 1<br>e9 |                 |         |        |       |                 |       |              |                | _      |
| 7  | 24   |                                  |                                  |      | (           | 0 1.6885E-12 | 1.688E-12     |      | "       |                 |         |        |       |                 |       |              |                | _      |
| 8  | 25   | i                                |                                  |      | (           | 0 1.5721E-12 | 1.572E-12     |      | 2       |                 |         |        |       |                 |       |              |                |        |
| 9  | 26   | i                                |                                  |      | (           | 0 1.465E-12  | 1.465E-12     |      | 1.0     |                 |         |        |       |                 |       |              |                |        |
| 0  | 27   | <u> </u>                         |                                  |      | (           | 0 1.3665E-12 | 1.367E-12     |      |         |                 |         |        |       |                 |       |              |                |        |
| 1  | 28   |                                  |                                  |      | (           | 0 1.2759E-12 | 1.276E-12     |      |         | /               |         |        |       |                 |       |              |                |        |
| 2  | 29   |                                  |                                  |      | (           | 0 1.1924E-12 | 1.192E-12     |      |         | /               |         |        |       |                 |       |              |                |        |
| 3  | 30   |                                  |                                  |      | (           | 0 1.1155E-12 | 1.116E-12     |      | 0.5     | 1               |         |        |       |                 |       |              |                |        |
| 4  | 31   |                                  |                                  |      | (           | 0 1.0447E-12 | 1.045E-12     |      |         | 1               |         |        |       |                 |       |              |                |        |
| 5  | 32   | 1                                |                                  |      | (           | 9.7942E-13   | 9.794E-13     |      |         | /               |         |        |       |                 |       |              |                |        |
| 6  | 33   |                                  |                                  |      | (           | 0 9.1923E-13 | 9.192E-13     |      |         | 1               |         |        |       |                 |       |              |                |        |
| 17 | 34   | l I                              |                                  |      | (           | 0 8.6371E-13 | 8.637E-13     |      | 0.0     |                 | -       |        |       |                 |       |              |                |        |
| 8  | 35   | i                                |                                  |      | (           | 0 8.1248E-13 | 8.125E-13     |      | 0       | 1               | 20      | 4      | υ.    | 60              |       | 80           | 100 -          |        |
| 9  | 36   | i                                |                                  |      | (           | 0 7.6521E-13 | 7.652E-13     |      |         |                 |         |        |       | rears           |       |              |                |        |
| 10 | 37   | 1                                |                                  |      | (           | 0 7.2157E-13 | 7.216E-13     |      |         |                 |         |        |       |                 |       |              |                |        |
| 11 | 20   |                                  |                                  |      |             | 6 91365 13   | 6 9125 12     |      |         |                 |         |        |       |                 |       |              |                |        |

## Thanks

- Contact
  - Email: gs1@cmu
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- Contribute to development or log an issue
  - github.com/gschivley/ghgforcing
  - github.com/gschivley/easyghg

