Cumulative Global Surface Temperature Change Values Associated With Global CH_4, CO_2, and N_2O Emissions And Livestock-Related GHG Emissions, 1950 -2016. By Todd Shuman, Senior Analyst, WUMU-WURU, 06/30/2017.

Introduction

The effect of anthropogenic greenhouse gas (GHG) emissions on global surface temperatures remains a topic of great concern in the world today. GHG emissions associated with global livestock and dairy production chains also remain a topic of substantial concern. The following analysis attempts to address two questions related to these crucial discourses. How much of the rise in global surface temperature values can be attributed to the positive radiative forcing associated with cumulative anthropogenic CH_4, CO_2, and N_2O emissions during the 1950-2016 period? How much of the rise in global surface temperature values can be attributed to the positive radiative forcing associated with anthropogenic CH_4, CO_2, and N_2O emissions *that have been discharged by global livestock supply chains (LSSC)* during the 1950-2016 period?

Possible answers to the former question may be inferred from data and temperature modeling software tools that can be accessed at the National Aeronautical Science Administration/Goddard Institute for Space Studies (NASA/GISS) website. For context, a *net* rise of +0.90/+0.67 degrees Celsius in global land/global land-ocean temperatures during the 1962-2012 period (relative to a year 1900 land/land-ocean value modeled at 0 degrees Celsius) can be identified using such data and tools. (Source: https://data.giss.nasa.gov/gistemp/maps/ [GISS Surface Temperature Analysis and Global Maps from GHCN v3 Data]. For more information concerning the +0.90/+0.67 values above, see **Additional Notes** below for Page 1.

Possible answers to the latter question may be inferred from Gerber et al. (2013) and Goodland and Anhang (2009). The former analysis suggests a 14.5% value, while the latter analysis suggests a 51% value. Both of these analyses use a Global Warming Potential (GWP) metric to assess the contributory atmospheric heat-trapping effects of livestock-related carbon dioxide, methane, and nitrous oxide emissions. The former analysis uses a 100-year time interval for methane emission (GWP 25, p. 106) while the latter uses a 20-year time interval for methane emission (GWP 72, p. 13). Both analyses are premised upon the conversion of all global GHG emissions into carbon dioxide equivalencies for comparison and accounting purposes.

GWP and GTP

With respect to associated global surface temperature change, the two livestock-related analyses referenced above are limited in their utility, due to their reliance upon (and application of) the GWP metric, which provides information concerning gross estimates of radiative forcing caused by GHG emissions. The GWP metric does not provide comprehensive information concerning "downstream" global surface temperature values that may be determined by a broad array of physical processes.

Moreover, recent critiques concerning overuse, misuse, and inappropriate application of the GWP metric (Pierrehumbert [2014], Allen et al. [2016]) suggest that the questions posed above might be more accurately answered through analysis that applies a different GHG-related metric.

In the analysis provided below, I attempt to answer the questions posed above by drawing upon the recent work of Allen et al. (2016) -- specifically Figure 2d. [See http://sequoiaforestkeeper.org/pdfs/attachments/Allen_et_al_on_SLCP_GWP_2016.pdf.] Figure 2d of Allen et al. (2016) presents graphed GHG/surface temperature change curves that are derived through the application of the Global Temperature Potential (GTP) metric.* These graphed curves provide directly-correlated GHG emission/surface temperature change values projected 100 years into the future following estimated year 2011 global anthropogenic CH_4, CO_2, and N_2O emissions. (See Appendix C.)

While the values in Figure 2d project future global surface temperature change impacts associated with a *single* year 2011 GHG emission (modeled as a pulse – or a cumulative 2011 value emitted all at once), Allen et al. (2016) also present (in Figure 2e) the projected global surface temperature change impact of annual GHG emissions *sustained indefinitely* in subsequent years at a constant 2011 emission rate. (In fact, Figure 2e projects such constant annual emission levels for 100 years into the future, starting from year 2011).

In the analysis provided below, I work backward in time, as opposed to working forward in time, as Allen et al. (2016) did in Figure 2e. I use a variety of source materials to conservatively reconstruct *annual* global anthropogenic $CH_4/CO_2/N_2O$ emission estimates for the 1950-2016 period. I then apply estimated mathematical factors to derive global surface temperature change values that can be reasonably associated with estimated annual global anthropogenic $CH_4/CO_2/N_2O$ emissions for the different periods within the overall 67 year time frame.** These annual global surface temperature change values are then aggregated over time to provide *cumulative* annual global surface temperature change values associated with *cumulative* global anthropogenic $CH_4/CO_2/N_2O$ emissions over the 1950-2016 period, as well as projected *future* global surface temperature change values related to these prior anthropogenic GHG emissions.***

*For more on the GTP metric, see the notes on lines 179-193 of Sheet 2 of the associated spreadsheet set. The GTP metric does account for heat uptake by the oceans and the delayed re-emission of heat previously absorbed by the oceans.

** The mathematical factors used in this study are both unitary and fractional values, and application of these factors generates temperature change values that are directly proportional to those values represented in the three graphed curves presented in Figure 2d of Allen et al. (2016).

***These annual and aggregated temperature change values for each estimated yearly global GHG emission are presented in full in the associated spreadsheet set. (See also Figure 2d with grid superimposed in Appendix C.) Extensive documentation concerning the scientific studies and sources that constitute the rationale for the values selected is presented in Sheet 2. For this text document, I note that all demarcated, typically-decadal period emission values for CH_4 (see Sheet 1) are less than the minimum EDGAR v4.2 CH_4 emission values for each associated typically-decadal GHG emission period (see Sheet 2). All period emission values for CO_2 (see Sheet 3) are drawn from the following sources: Table 6.1 [p 486], Page 489, Part 1, Chapter 6, IPCC AR5 (2013); and Peters, G.P. et al. (Dec, 2012) for the 1980-2011 period; Boden et al. (2016) and Figure 6.8 in part 1, Chapter 6, IPCC AR5 (2013) for the 1950-1980 period. All period emission values for N_2O (see Sheet 4) are based upon material provided in Table 6.9 of Chapter 6, IPCC AR5 (2013) and the EDGAR v4.2 database. For a more complete disclosure of methodology and additional information, see Appendix 1. For more on EDGAR, see http://edgar.jrc.ec.europa.eu/overview.php?v=42FT2010?. (Note: downloading of the v4.2 FT2012 1970-2012 GHG dataset is not currently enabled at the EDGAR website.)

Analysis Summary

This analysis indicates that cumulative anthropogenic CH_4, CO_2, and N_2O emissions over the 1950-2016 period likely increased *gross* 2015 and 2016 annual global mean surface temperatures approximately 1.5 degrees Celsius above what such global mean surface temperatures would otherwise have been.* (See Lines 31/67 in Tables A and B below for year 2016.)

This analysis also indicates that global-livestock-supply-chain-associated GHG emissions (CH_4, CO_2, and N_2O only) over this 67 year period are likely responsible for roughly one-fifth (20.5%) of these *gross* 1.5 degrees Celsius annual global mean surface temperature increases for 2015 and 2016. (See Line 40, Table A below, for year 2016.)

The livestock-related value *excludes* foregone carbon sequestration due to the conversion of forests into pastures and livestock feed crop [LFC] production. If foregone carbon sequestration is included (and added) into the "equation," the livestock-supply-chain (LSSC) share of the total increases to roughly a quarter

(25.5%) of the *gross* global mean surface temperature rise associated with the cumulative anthropogenic CH_4, CO_2, and N_2O emissions that have occurred since 1950. (See Line 76, Table B below, for year 2016.)[1]

* Excluded from the analysis are the effects of negative atmospheric climate forcers [or atmospheric climate cooling agents, such as SO_2]. Thus, the term *gross* is used to indicate "before deduction", or before temperature change value deductions due to the effects of negative forcing agents are factored into the overall "equation".

Also excluded from the analysis are the effects of other positive climate forcers such as black carbon (BC) and fluorinated gases (F-gases). Exclusion of LSSC-related black carbon/fluorinated gas emission shares from this analysis likely imparts a further conservative bias to this study. Coal/Biofuel/Diesel-associated black carbon emissions and refrigeration-associated fluorinated gas emissions undoubtedly constitute a part of global LSSC-related emissions that should be incorporated into future analyses.

1: Goodland, in 2013, argued: "The FAO's analysis [i.e., Gerber et al. (2013)] also omits counting carbon dioxide from livestock respiration. Yet reality no longer reflects the old model of the carbon cycle, in which photosynthesis (carbon intake) balanced respiration (carbon emission). That model was valid as long as there were roughly constant levels of respiration and photosynthesis on Earth. But in recent decades, respiration has increased exponentially as livestock production has intensified (now totaling more than 60 billion animals raised on land every year). This has been accompanied by large-scale deforestation and forest-burning, in large part to graze livestock and grow crops for them, leading to huge increases in carbon emissions and a dramatic decline in Earth's photosynthetic capacity, and therefore in its capacity to sequester greenhouse gas. As a result, either carbon dioxide released via livestock respiration – or *carbon absorption forgone on land set aside for livestock and feed production – should be counted as emissions.*" (http://www.earthisland.org/journal/index.php/elist/eListRead/fao_underplays_impact_of_livestock_industry_emissions/.) [Italics added]

While I remain agnostic (and perhaps even skeptical) concerning Goodland's cattle respiration claim, I concur with Goodland that foregone CO_2 sequestration due to forest conversion into pasture and livestock feed crop [LFC] production should be included in (and added into) an overall accounting of livestock GHG emissions and emission-related surface temperature change impacts. See Appendix B (LSSC/Forest Conversion-Related Foregone CO_2 Sequestration) for more information concerning this matter.

Table A: Summary of Global Mean Surface Temperature Change Values Associated with Global Anthropogenic CH_4, CO_2, and N_2O Emissions and Global Livestock-Related GHG Emissions [based only on LSSC GHG proportions presented in Gerber et al. (2013)]. Foregone CO_2 Sequestration Due To Forest Conversion to Pasture and livestock feed crop [LFC] Production **is excluded**. (Summary Table below copied from Sheet 1 in associated spreadsheet set titled "Anthropogenic GHG Emissions and Global Surface Temperature Change Values, 1950-2016." Line# from Sheet 1. (Surface Temperature Change Values In Degrees Celsius [C].)

	Line# Note	2015	2016	2017	2018	2019	2020	2021
CH_4	16	0.518967	0.523877	0.528611	0.531666	0.531087	0.525344	0.51492
	17	0.44	0.44	0.44	0.44	0.44	0.44	0.44
LSSC CH_4	18	0.228346	0.230506	0.232589	0.233933	0.233678	0.231152	0.226565
CO_2	20	0.892189	0.915205	0.9384	0.960356	0.978961	0.992684	1.001991
	21	0.05	0.05	0.05	0.05	0.05	0.05	0.05
LSSC CO_2	22	0.044609	0.04576	0.04692	0.048018	0.048948	0.049634	0.0501
N_20	24	0.054023	0.055118	0.056211	0.057208	0.058107	0.058805	0.059243
	25	0.53	0.53	0.53	0.53	0.53	0.53	0.53
LSSC N_2O	26	0.028632	0.029212	0.029792	0.03032	0.030797	0.031166	0.031399
CH_4	28	0.518967	0.523877	0.528611	0.531666	0.531087	0.525344	0.51492
CO_2	29	0.892189	0.915205	0.9384	0.960356	0.978961	0.992684	1.001991
N_20	30	0.054023	0.055118	0.056211	0.057208	0.058107	0.058805	0.059243
GHG Total	31	1.465179	1.4942	1.523222	1.54923	1.568154	1.576833	1.576155
LSSC CH_4	33	0.228346	0.230506	0.232589	0.233933	0.233678	0.231152	0.226565
LSSC CO_2	34	0.044609	0.04576	0.04692	0.048018	0.048948	0.049634	0.0501
LSSC N_2O	35	0.028632	0.029212	0.029792	0.03032	0.030797	0.031166	0.031399
LSSC Total	36	0.301588	0.305479	0.309301	0.312271	0.313423	0.311952	0.308064
LSSC Total	38	0.301588	0.305479	0.309301	0.312271	0.313423	0.311952	0.308064
GHG Total	39	1.465179	1.4942	1.523222	1.54923	1.568154	1.576833	1.576155
38/39	40	20.58%	20.44%	20.31%	20.16%	19.99%	19.78%	19.55%

Table B: Summary of Global Mean Surface Temperature Change Values Associated with Global Anthropogenic CH_4, CO_2, and N_2O Emissions and Global Livestock-Related GHG Emissions [based primarily on LSSC GHG proportions presented in Gerber et al. (2013)]. Foregone CO_2 Sequestration Due To Forest Conversion to Pasture and Livestock Feed Crop [LFC] Production **is included**. (Summary Table below copied from Sheet 1 in associated spreadsheet set titled "Anthropogenic GHG Emissions and Global Surface Temperature Change Values, 1950-2016." Line# from Sheet 1. (Surface Temperature Change Values In Degrees Celsius [C].)

	Line# Note	2015	2016	2017	2018	2019	2020	2021
CH_4	52	0.518967	0.523877	0.528611	0.531666	0.531087	0.525344	0.51492
	53	0.44	0.44	0.44	0.44	0.44	0.44	0.44
LSSC CH_4	54	0.228346	0.230506	0.232589	0.233933	0.233678	0.231152	0.226565
CO_2	56	0.892189	0.915205	0.9384	0.960356	0.978961	0.992684	1.001991
	57	0.132	0.132	0.132	0.132	0.132	0.132	0.132
LSSC CO_2	58	0.117769	0.120807	0.123869	0.126767	0.129223	0.131034	0.132263
N_2O	60	0.054023	0.055118	0.056211	0.057208	0.058107	0.058805	0.059243
	61	0.53	0.53	0.53	0.53	0.53	0.53	0.53
LSSC N_2O	62	0.028632	0.029212	0.029792	0.03032	0.030797	0.031166	0.031399
CH_4	64	0.518967	0.523877	0.528611	0.531666	0.531087	0.525344	0.51492
CO_2	65	0.892189	0.915205	0.9384	0.960356	0.978961	0.992684	1.001991
N_2O	66	0.054023	0.055118	0.056211	0.057208	0.058107	0.058805	0.059243
GHG Total	67	1.465179	1.4942	1.523222	1.54923	1.568154	1.576833	1.576155
LSSC CH_4	69	0.228346	0.230506	0.232589	0.233933	0.233678	0.231152	0.226565
LSSC CO_2	70	0.117769	0.120807	0.123869	0.126767	0.129223	0.131034	0.132263
LSSC N_2O	71	0.028632	0.029212	0.029792	0.03032	0.030797	0.031166	0.031399
LSSC Total	72	0.374747	0.380526	0.386249	0.391021	0.393698	0.393352	0.390227
LSSC Total	74	0.374747	0.380526	0.386249	0.391021	0.393698	0.393352	0.390227
GHG Total	75	1.465179	1.4942	1.523222	1.54923	1.568154	1.576833	1.576155
74/75	76	25.58%	25.47%	25.36%	25.24%	25.10%	24.95%	24.76%

Line# Notes from Sheet 1 associated with Table A and Table B above:

16/52: Select Global Surface Temperature Change Values Associated With Cumulative Anthropogenic Methane Emissions (1950-2016); Degrees C

17/53: Livestock-Related (Enteric, Manure, and Other) Factor Share [4/9 approx] Of Total Methane Emission Pulse: Based on Gerber et al. (2013), Page 15. [Gerber et al. include "upstream" and "downstream" CH_4 emission sources in the livestock supply chain. (Enteric and manure sources are considered neither "upstream" nor "downstream" - they are classified within the "animal production unit" category - see page 7.]

18/54: Global Surface Temperature Change Values Associated With Cumulative Anthropogenic Livestock-Related CH_4 Emissions (1950-2016), in Degrees C. Livestock Supply Chains are associated with 44% of Total Anthropogenic CH_4 Emissions in year 2005 - Source: Gerber, et al. (2013), page 15 and Sheet 1

20/56: Select Global Surface Temperature Change Values Associated With Cumulative Anthropogenic Carbon Dioxide Emissions (1950-2016); Degrees C

21: Livestock-Related Factor Share [1/20 approx] Of Total Carbon Dioxide Emission Pulse -- Source: Gerber et al. (2013), page 15.

22: Global Surface Temperature Change Values Associated With Cumulative Anthropogenic Livestock-Related CO_2 Emissions (1950-2016), in Degrees C. Livestock Supply Chains are associated with 5% of Total Anthropogenic CO_2 Emissions in year 2005 -- Source: Gerber, et al. (2013), page 15 and Sheet 3

24/60: Select Global Surface Temperature Change Values Associated With Cumulative Anthropogenic Nitrous Oxide Emissions (1950-2016); Degrees C

25/61: Livestock-Related Factor Share [53/100 approx] Of Total Nitrous Oxide Emission Pulse – Source: Gerber et al. (2013), page 15.

26/62: Global Surface Temperature Change Values Associated With Cumulative Anthropogenic Livestock-Related N_2O Emissions (1950-2016), in Degrees C. Livestock Supply Chains are associated with 53% of Total Anthropogenic N_2O Emissions in year 2005 -- Source: Gerber et al. (2013), page 15 and Sheet 4.

28/64: Global Surface Temperature Change Values Associated With Cumulative Anthropogenic CH_4 Emissions (1950-2016), in Degrees C.

29/65: Global Surface Temperature Change Values Associated With Cumulative Anthropogenic CO_2 Emissions (1950-2016), in Degrees C.

30/66: Global Surface Temperature Change Values Associated With Cumulative Anthropogenic N_2O Emissions (1950-2016), in Degrees C.

31/67: Global Surface Temperature Change Values Associated With Cumulative Anthropogenic Emissions (1950-2016), in Degrees C [CH_4+CO_2+N_2O]

33/69: Global Surface Temperature Change Values Associated With Cumulative Anthropogenic Livestock-Related CH_4 Emissions (1950-2016), in Degrees C. Livestock Supply Chains are associated with 44% of Total Anthropogenic CH_4 Emissions in year 2005 -- Source: Gerber, et al. (2013), page 15 and Sheet 1

34: Global Surface Temperature Change Values Associated With Cumulative Anthropogenic Livestock-Related CO_2 Emissions (1950-2016), in Degrees C. Livestock Supply Chains are associated with 5% of Total Anthropogenic CO_2 Emissions in year 2005 -- Source: Gerber, et al. (2013), page 15 and Sheet 3

35/71: Global Surface Temperature Change Values Associated With Cumulative Anthropogenic Livestock-Related N_20 Emissions (1950-2016), in Degrees C. Livestock Supply Chains are correlated with 53% of Total Anthropogenic N_2O Emissions in year 2005 -- Source: Gerber, et al. (2013), page 15 and Sheet 4

36/72: Global Surface Temperature Change Values Associated With Cumulative Anthropogenic Livestock-Related Emissions (1950-2016), in Degrees C [CH_4+CO_2+N_2O]

38/74: Global Surface Temperature Change Values Associated With Cumulative Anthropogenic Livestock-Related Emissions (1950-2016), in Degrees C [CH_4+CO_2+N_2O]

39/75: Global Surface Temperature Change Values Associated With Cumulative Anthropogenic Emissions (1950-2016), in Degrees C [CH_4+CO_2+N_2O]

40/76: Livestock Supply Chain Emission-Related Temperature Change Values [CH_4+CO_2+N_2O] As A Proportion [%] of Total Cumulative Anthropogenic CH_4+CO_2+N_2O Emission-Related Temperature Change Values (1950-2016 period)

57: Livestock-Related Factor Share [132/1000 approx] Of Total Carbon Dioxide Emission Pulse. This value is based on Gerber et al. (2013), page 15 and Goodland and Anhang (2009, pages 11 and 15). (The Gerber value of 5% is added to estimated foregone CO_2 sequestration value of 8.2%. The 8.2% value is derived from the estimated foregone CO_2 sequestration value presented in Goodland and Anhang [2009], divided by the global annual mean CO_2 emission value for 2000-2010, derived from Table 6.1 (page 486), Chapter 6, Part 1, IPCC, 2013. [2.672 Gt/32.6 Gt=8.2%. 32.6 Gt is 8.9 GtC multiplied by 3.667, which yields 32.6 $GtCO_2$. Note: 32.6 $GtCO_2$ is 8.9 GtC multiplied by 3.667. 3.667 is the factor used to convert a carbon-only mass quantity into a carbon dioxide mass quantity. Atomic Mass of C=12, CO_2=44; $12*3.667=44$.])

58: Global Surface Temperature Change Values Associated With Cumulative Anthropogenic Livestock-Related CO_2 Emissions (1950-2016), in Degrees C. Livestock Supply Chains are associated with 13.2% of Total Anthropogenic CO_2 Emissions. This value is based on Gerber et al. (2013) [page 15] and Goodland and Anhang (2009, pages 11, 15). (The Gerber value of 5% is added to estimated foregone CO_2 sequestration value of 8.2%. The 8.2% value is derived from the estimated foregone CO_2 sequestration value presented in Goodland and Anhang [2009], divided by the global annual mean CO_2 emission value for 2000-2010, derived from Table 6.1[page 486], Chapter 6, Part 1, IPCC, 2013. [2.672 Gt CO_2e/32.6 GtCO_2=8.2%. Note: 32.6 GtCO_2 is 8.9 GtC multiplied by 3.667. 3.667 is the factor used to convert a carbon-only mass quantity into a carbon dioxide mass quantity. Atomic Mass of C=12, CO_2=44; 12*3.667=44.])

70: Global Surface Temperature Change Values Associated With Cumulative Anthropogenic Livestock-Related CO_2 Emissions (1950-2016), in Degrees C. Livestock Supply Chains are associated with 13.2% of Total Anthropogenic CO_2 Emissions. This value is based on Gerber et al. (2013) [page 15] and Goodland and Anhang (2009, pages 11, 15). (The Gerber value of 5% is added to estimated foregone CO_2 sequestration value of 8.2%. The 8.2% value is derived from the estimated foregone CO_2 sequestration value presented in Goodland and Anhang [2009], divided by the global annual mean CO_2 emission value for 2000-2010, derived from Table 6.1 [page 486], Chapter 6, Part 1, IPCC, 2013. [2.672 Gt CO_2e/32.6 GtCO_2=8.2%. 32.6 GtCO_2 is 8.9 GtC multiplied by 3.667.])

Additional Notes:

Page 1: For the 1962–2012 period:+0.90/+0.67 degree Celsius rise for global land/land-ocean combined

1958-1965 (1962)	1988-1995 (1992)	2008-2015 (2012)	relative to 1880-1920 (1900)
0.36/0.27	0.80/0.62	1.26/0.94	relative to 1900 land/land-ocean value of 0 degrees C

1962-1992 increase: +0.44/+0.35; 1992-2012 increase: +0.46/+0.32;

1962-2012 increase +0.90/+0.67

Source: http://data.giss.nasa.gov/gistemp/maps/. [Note: Todd Shuman consulted with Dr. Ron Miller, Deputy Chief of Lab, NASA Goddard Institute of Space Studies concerning proper parameters for input. Dr. Miller recommended "smoothing" anomalies over 7-year time frames; use Anomalies, not Trend; define Mean Period as Annual (Jan-Dec); defined base period 1880-1920 was considered reasonable. Use 1200 KM Smoothing Radius, and Robinson Map Projection. For Land: use GISS analysis; For Ocean: use ERSST v.4.]

Gerber, P.J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A. & Tempio, G. 2013. Tackling climate change through livestock – A global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations (FAO), Rome. [Page 15].

Goodland and Anhang, 2009, World Watch, Nov/Dec, 2009, page 11 and 13, "Livestock and Climate Change", World Watch Magazine, November/December, Volume 22, No. 6.

“Short-Lived Climate Pollution”, R.T. Pierrehumbert, Annu. Rev. Earth Planet. Sci. 2014. 42:341–79, page 374-375.

“New use of global warming potentials to compare cumulative and short-lived climate pollutants,” Myles R. Allen, Jan S. Fuglestvedt, Keith P. Shine, Andy Reisinger, Raymond T. Pierrehumbert and Piers M. Forster, Nature Climate Change, PUBLISHED ONLINE: 2 MAY 2016 | DOI: 10.1038 /NCLIMATE 2998, Figure 2d http://sequoiaforestkeeper.org/pdfs/attachments/Allen_et_al_on_SLCP_GWP_2016.pdf.

Myhre, G. et al. in Climate Change 2013: The Physical Science Basis (eds Stocker, T. F. et al.) Ch. 8 .(IPCC, Cambridge Univ. Press, 2013).

Ciais, P., C. Sabine, G. Bala, L. Bopp, V. Brovkin, J. Canadell, A. Chhabra, R. DeFries, J. Galloway, M. Heimann, C. Jones, C. Le Quéré, R.B. Myneni, S. Piao and P. Thornton, 2013: Carbon and Other Biogeochemical Cycles. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Peters, G. P., et al., 2013: The challenge to keep global warming below 2°C. Nature Clim. Change, 3, 4–6.

Boden, T.A., G. Marland, and R.J. Andres. 2016. *Global, Regional, and National Fossil-Fuel CO_2 Emissions*. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, TN, USA. doi 10.3334/CDIAC/00001_V2016, http://cdiac.ornl.gov/trends/emis/tre_glob_2013.html (accessed March 5, 2017).

Appendix A: Study Methodology

The method used to derive numerical values for the lines (16/52, 20/56, and 24/60) on both Table A and Table B (pdf text document) and the spreadsheet set tables near the top of Sheet 1 is presented below.

Values on Lines 81-85 (Sheet 1), Lines 1-4 (Sheet 3), and Lines 1-4 (Sheet 4) are estimated future annual global surface temperature change (EFAGSTC) values associated with year 2011 global anthropogenic GHG pulse emissions for CH_4, CO_2, and N_2O. These numerical values are estimated through superimposition of a grid on Figure 2d. (See Figure 2d with grid superimposed in Appendix C.) The graphs in figure 2d are derived largely through use of the GTP metric. (See Allen et al. [2016].)

The year 2011 EFAGSTC values for CH_4 are applied for the years 2006-2016. The year 2011 EFAGSTC values for CO_2 and N_2O are applied for the years 2011-2016. (Contact author for further information concerning this matter. Significant variation among the authoritative data sources for these three different GHG emissions led to the analytic choices made for this study.)

For earlier typically-decadal periods (going back to 1950), EFAGSTC values for CH_4, CO_2, and N_2O are reduced relative to year 2011 EFAGSTC-associated values by multiplying the 2011 EFAGSTC-associated values by a factor that corresponds to the fraction of that decade's GHG emission (in terms of mass) *relative to the year 2011 GHG emission* (in terms of mass, as specified by Allen et al. [2016]). These factors are based upon information from a number of different authoritative sources that provide estimated mean anthropogenic GHG emission values (in terms of mass) for the pre-2011 decadal periods. (See notes in Sheet 2 of spreadsheet set.) The factors (which are correlated with estimated emission values for a particular typically decadal period) are smallest in 1950, and the increase over the 1950-2016 period is modeled in quantum fashion until achieving unity during the 2006-2016 period for CH_4 and 2011-2016 period for CO_2 and N_2O. This reduction is calculated and represented in lines 87-119 (Sheet 1), 6-44 (Sheet 3), and 6-44 (Sheet 4).

[All the EFAGSTC values for associated estimated annual CH_4, CO_2, and N_2O emissions during the 1950-2016 are presented on lines 125-193 (Sheet 1), 52-118 (Sheet 3), and 52-118 (Sheet 4). All of these annual EFAGSTC values are added together using the automatic spreadsheet sum function on line 195 (Sheet 1), line 120 (Sheet 3), and line 120 (Sheet 4). The summed 2016 value for CH_4 over the complete 1950-2016 period is located in cell BP 195 of Sheet 1. The summed 2016 values for CO_2 and N_2O are located in cells BP 120 of Sheets 3 and 4.]

Appendix B: LSSC/Forest Conversion-Related Foregone CO_2 Sequestration

1: The annual global LSSC/forest conversion-related foregone CO_2 sequestration value used in this study is 8.2% of estimated annual anthropogenic CO_2 emissions throughout the 1950-2016 period. The 8.2% value is derived through use of an estimated annual global foregone CO_2 sequestration value presented in Goodland and Anhang [2009], divided by the global annual mean anthropogenic CO_2 emission value for 2000-2010, (which was derived from Table 6.1 [page 486], Chapter 6, Part 1, IPCC, 2013). [2.672 Gt CO_2/32.6 GtCO_2=8.2%. 32.6 GtCO_2 is 8.9 GtC multiplied by 3.667.]

Goodland and Anhang (2009) do not disclose an explicit accounting of their derivation method for their 2.672 Gt CO_2 value. Moreover, a reasonable, relatively straight-forward global estimate (with disclosed, explicit accounting) concerning this topic is not readily available, after extensive search. Nonetheless, information disclosed in Myers (1980), Aragao et al. (2014), de Haan et al. (1997), Opio et al. (2013), Potapov et al. (2017), and other sources disclosed in Supplemental Material Concerning Deforestation Associated with Pasture or Livestock Feed Crop Expansion, Presented in Appendix B of *Global Surface Temperature Change Values Associated With Global CH_4, CO_2, and N_2O Emissions As Well As Global Livestock-Related GHG Emission [author: Todd Shuman, Senior Analyst, WUMU-WURU, 05/02/17]* suggests that use of the 2.672 Gt value constitutes a reasonable (and conservative) estimate of annual *global* LSSC/forest conversion-related foregone CO_2 sequestration over the 2000-2010 period.

A conservative, partial estimate of cumulative Latin-American (L.A.) foregone CO_2 sequestration for the period **1966-2006** -- based upon *explicitly-attributed* LSSC-related L.A. deforestation -- is 1.825722 Gt. This amount is 68.33% of the annual global LSSC-related foregone CO_2 sequestration value for the 2000-2010 reference period used in this study [2.672 Gt, or 8.2 % of 32.6 Gt]. Accounting is below:

375.5 million metric tonnes foregone CO_2 sequestration [1966-1978, Brazil]

[Annual global carbon sequestration by intact primary forest landscapes in 1979 would have been 375.5 MMT less than in 1965.]

289.455 million metric tonnes foregone CO_2 sequestration [1980-1989, L.A.]

[Annual global carbon sequestration by intact primary forest landscapes in 1990 would have been (375.5 MMT plus 289.455 MMT) less than in 1965.]

1,160.767 million metric tonnes foregone CO_2 sequestration [1990-2006, L.A.]

[Annual global carbon sequestration by intact primary forest landscapes in 2007 would have been (375.5 MMT plus 289.455 MMT plus 1,160.767 MMT) less than in 1965.]

1825.722 million metric tonnes (MMT) foregone CO_2 sequestration total [1966-2006, L.A.]
1825.722 $MMTCO_2$/2,672 $MMTCO_2$ = 68.33%

A conservative, partial estimate of cumulative Latin-American (L.A.) foregone CO_2 sequestration for the period **1966-2013** -- based upon *explicitly-attributed* LSSC-related L.A. deforestation -- is 2.092467 Gt. This amount is 67.24% of the estimated annual global LSSC-related foregone CO_2 sequestration value for the 2011-2016 period [3.116 Gt, or 8.2% of 38 Gt]. Accounting is below:

1825.722 million metric tonnes foregone CO_2 sequestration [1966-2006, L.A.]
266.745 million metric tonnes foregone CO_2 sequestration [2007-2013, L.A.]

[Annual global carbon sequestration by intact primary forest landscapes in 2014 would have been (375.5 MMT plus 289.455 MMT plus 1,150.767 MMT plus 266.745MMT) less than in 1965.]

2092.467 million metric tonnes (MMT) foregone CO_2 sequestration (total)
2092.467 $MMTCO_2$ /3,112 $MMTCO_2$ = 67.24%

2. Authoritative estimates of Brazilian LSSC-related tropical forest conversion into pasture *over the 1966-1978 period* are found within Myers (1980).

["Between 1966 and 1978, 80,000 km^2 of Brazil's Amazonian forests were converted into 336 cattle ranches supporting 6 million head of cattle, under auspices of the Superintendency for Development of Amazonia (SUDAM). In addition, some 20,000 other ranches of varying size have been established. … According to the Superintendencia do Desenvolvimento da Amazonia (SUDAM) (C. Pandolfo, personal communication, SUDAM, Belem. Brazil, 1978), from 1966 to 1978, 80,000 km^2 of Amazonian forestlands were converted to cattle pasture in the form of 336 ranching projects under the auspices of SUDAM, together with some 20,000 other ranches of varying size." Page 44 and pages 123-124.]

Multiplying the mean forest carbon sequestration/ha value presented in Aragao et al. (2014) with the LSSC-driven deforestation area value derived from Myers (1980) and the 3.667 carbon-to-CO_2 conversion constant yields the following result: 375.5 million metric tonnes of Latin American-based, tropical forest-based CO_2 sequestration foregone *annually* due to the LSSC-driven, pasture-related forest elimination that occurred in Latin America during the 1966-1978 period.

South American (SA) cumulative deforestation area: 80,000 km^2 = 8,000,000 ha of forest converted into pasture.

Calculation sequence:
$1.28 * 10^1$ Mg C/ha $* 8.0 * 10^6$ ha $* 3.667 = 37.55 * 10^7 = 3.755 * 10^8$ =
375,500,000 metric tonnes of foregone CO_2 sequestration, or
375.5 million metric tonnes CO_2

Sources: U.S. Department of Agriculture, 1978, found in *Conversion of Tropical Moist Forests*, Myers, N. (1980), Pages 44,123,124; Myers, Norman; Committee on Research Priorities in Tropical Biology; National Research Council, pages 44 and 46, http://www.nap.edu/catalog.php?record_id=19767.

Environmental change and the carbon balance of Amazonian forest. Luiz E. O. C. Aragao, Benjamin Poulter, Jos B. Barlow, Liana O. Anderson, Yadvinder Malhi, Sassan Saatchi, Oliver L. Phillips, and Emanuel Gloors 8 Biol. Rev. (2014), **89**, pp. 913–931, doi: 10.1111/brv.12088.

[Note: Annual global carbon sequestration by intact primary forest landscapes in 1979 would have been 375.5 MMT less than in 1965.]

3. Authoritative estimates of *Latin American* LSSC-related tropical forest conversion into pasture *over the 1980-1989 period* have been provided by de Haan, Steinfeld, and Blackburn (1997).

["In Central America in the 1980s rainforests disappeared at the rate of 430 thousand hectares per year. ... In South America, the deforestation rate in the 1980s was about 750 thousand hectares per year. … Much of the deforested areas in Latin America went into ranching, sometimes after initially being cropped."]

Multiplying the mean forest carbon sequestration/ha value presented in Aragao et al. (2014) with the LSSC-driven deforestation area value derived from de Haan et al. (1997) and the 3.667 carbon-to-CO_2 conversion constant yields the following result: 289.455 million metric tonnes of Latin American-based, tropical forest-based CO_2 sequestration foregone *annually* due to the LSSC-driven, pasture-related forest elimination that occurred in Latin America during the 1980-1989 period.

South American (SA) deforestation rate (ha/yr): 750,000; 1980-1989 cumulative: 7.5 million hectares deforested. Conversion rate of forest into ranching/pasture, based on Bruenig (1991), is estimated at 44-70%.

Calculation sequence for SA:
$1.28 * 10^1$ Mg C/ha $* 7.5 * 10^6$ ha $* 0.44 * 3.667 = 15.489 * 10^7$, or $1.5489 * 10^8$
$1.28 * 10^1$ Mg C/ha $* 7.5 * 10^6$ ha $* 0.70 * 3.667 = 24.642 * 10^7$, or $2.4642 * 10^8$

Central America (CA) deforestation rate (ha/yr): 430,000; 1980-1989 cumulative: 4.3 million hectares deforested. Conversion rate of forest into ranching/pasture, based on Bruenig (1991), is estimated at 44%.

Calculation sequence for CA:
$1.28 * 10^1$ Mg C/ha $* 4.3 * 10^6$ ha $* 0.44 * 3.667 = 8.88 * 10^7$, or $0.888 * 10^8$

Total forest conversion-into pasture-related foregone CO_2 sequestration:

$1.5489 + 0.888 = 2.4369 * 10^8$, or 243.69 million metric tonnes CO_2 (SA-44%, CA-44%)
$2.4642 + 0.888 = 3.3522 * 10^8$, or 335.22 million metric tonnes CO_2 (SA-70%, CA-44%)

Mean value = $2.8945 * 10^8$, or 289.455 million metric tonnes CO_2 (SA-57%, CA-44%)

Sources: *Livestock & the Environment, Finding a Balance*, Cees de Haan, Henning Steinfeld, and Harvey Blackburn, 1997, Study Sponsors: Commission of the European Communities, Food and Agriculture Organization [UN], World Bank, Chapter 2; see Aragao et al. (2014) above.

[Note: Annual global carbon sequestration by intact primary forest landscapes in 1990 would have been (375.5 MMT plus 289.455 MMT) less than in 1965.]

4. Recent authoritative estimates of *Latin American* LSSC-related primary tropical forest conversion into pasture/LFC production *over the 1990-2006 period* have been provided by Opio et al. (2013).

[Opio et al.: "The reported annual increase of soybean area in Brazil is 534,000 ha. … We thus assume that all incremental soybean area is gained at the expense of forest area. … our estimates show that about 13 million hectares were deforested for pasture establishment. … In Argentina … 44 percent of the new soybean area was gained against other crops, while the rest was gained against forest (22 percent) and other land (31 percent)." The annual Argentine soybean area gained at the expense of forest area can be inferred from Opio et al. (2013) at 143,000 ha/yr. Therefore, LSSC-related forest conversion into soya/pasture land area in Latin America (1990-2006) is estimated at 11.51 million ha (soya) plus 13.2216 million ha (pasture). The summed conversion total for this period is 24.73 million hectares.]

Multiplying the mean forest carbon sequestration/ha value presented in Aragao et al. (2014) with the LSSC-driven deforestation area value derived from Opio et al. (2013) and the 3.667 carbon-to-CO_2 conversion constant yields the following result: 1,160.767 million metric tonnes of Latin American-based, tropical forest-based CO_2 sequestration foregone *annually* due to the LSSC-driven, soya/pasture-related forest elimination that occurred in Latin America during the 1990-2006 period.

[Calculation sequence: 12.8 Mg C ha^{-1} $year^{-1}$ $*$ 24,730,000 ha =
$1.28 * 10^1 * 2.473 * 10^7 = 3.16544 * 10^8$ Mg C; Mg = metric tonne
$3.16544 * 10^8 * 3.667 = 11.60767 * 10^8 = 1.160767 * 10^9$ metric tonnes CO_2 =
1,160,767,000 metric tonnes; or 1,160.767 million metric tonnes.]

Sources: *Greenhouse gas emissions from ruminant supply chains – A global life cycle assessmen.* Opio, C., Gerber, P., Mottet, A., Falcucci, A., Tempio, G., MacLeod, M., Vellinga, T., Henderson, B. & Steinfeld, H. 2013. Food and Agriculture Organization of the United Nations (FAO), Rome; see Aragao et al. (2014) above.

Supplemental Material Concerning Deforestation Associated with Pasture or Livestock Feed Crop Expansion, Presented in Appendix B of *Global Surface Temperature Change Values Associated With Global CH_4, CO_2, and N_2O Emissions As Well As Global Livestock-Related GHG Emission [author: Todd Shuman, Senior Analyst, WUMU-WURU, 04/18/17]*

[Note: Annual global carbon sequestration by intact primary forest landscapes in 2007 would have been (375.5 MMT plus 289.455 MMT plus 1,160.767 MMT) less than in 1965.]

5: Recent authoritative estimates of *Latin American* LSSC-related tropical forest conversion into pasture/LFC production *over the 2000-2013 period* have been provided by Potapov et al. (2017). Potapov provides information concerning LSSC-related destruction of intact forest landscapes (IFLs) between 2000 and 2013.

[Potapov et al.: "In particular, tropical South America lost 322,000 km^2 of IFL area. … Brazil (157,000 km^2) … In tropical South America, expansion of … pastures in particular contributed … 53% of the overall IFL area loss." Note: 322,000 km^2 = 32,200,000 hectares, or 32.2 million hectares.]

Multiplying the mean forest carbon sequestration/ha value presented in Aragao et al. (2014) with both the overall LSSC-driven IFL deforestation area value derived from Potapov and the 3.667 carbon-to-CO_2 conversion constant yields the following product: 801.0371 million metric tonnes of Latin American-based, tropical forest-based CO_2 sequestration foregone *annually* due to the cumulative LSSC-driven, pasture-related IFL forest elimination that occurred in Latin America during the 2000-2013 period.

[Calculation sequence: 12.8 Mg C ha^{-1} $year^{-1}$ $*$ 32,200,000 $*$ 0.53 =
$1.28 \cdot 10^1 * 3.22 * 10^7 * 0.53 = 2.184448 * 10^8$ Mg C; Mg = metric tonne of C
$2.184448 * 10^8 * 3.667 = 8.01037 * 10^8$; or 801,037,100 metric tonnes of CO_2
or 801.0371 million metric tonnes of foregone CO_2 sequestration.]

[Based upon these calculations, I estimate conservatively a foregone CO_2 sequestration value for the 2007-2013 period at 1/3 of the 2000-2013 Potapov-associated cumulative total value presented above, with 2/3 of the cumulative total value above excluded due to overlap with the period analyzed by Opio et al. (2013). See above.]

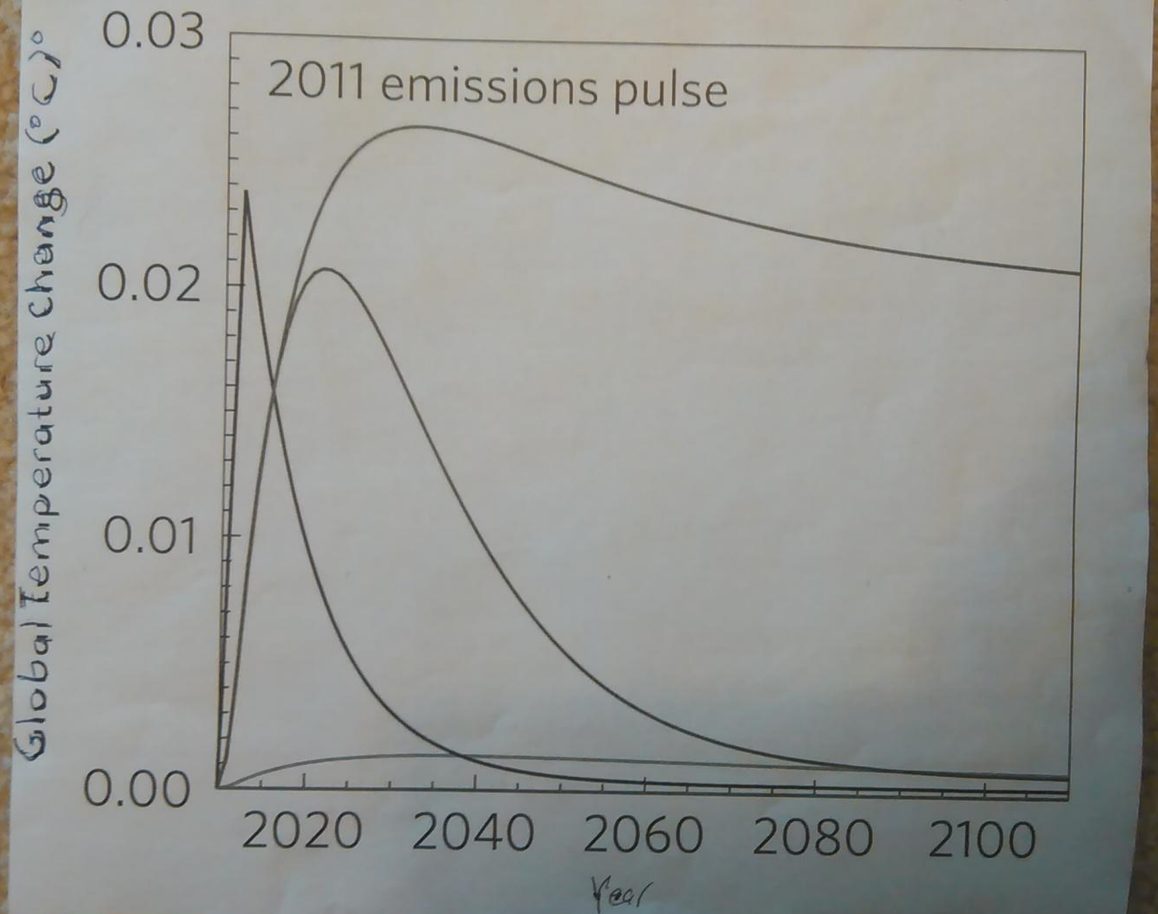
2007-2013: 1/3 of 801.0371 million metric tonnes of foregone CO_2 sequestration equals 266.745 million metric tonnes of foregone CO_2 sequestration.

Thus, 266.745 million metric tonnes of Latin American-based, tropical forest-based CO_2 sequestration have recently been (and will continue to be) foregone *annually* due to the LSSC-driven, soya/pasture-related forest elimination that occurred in Latin America during the 2007-2013 period.

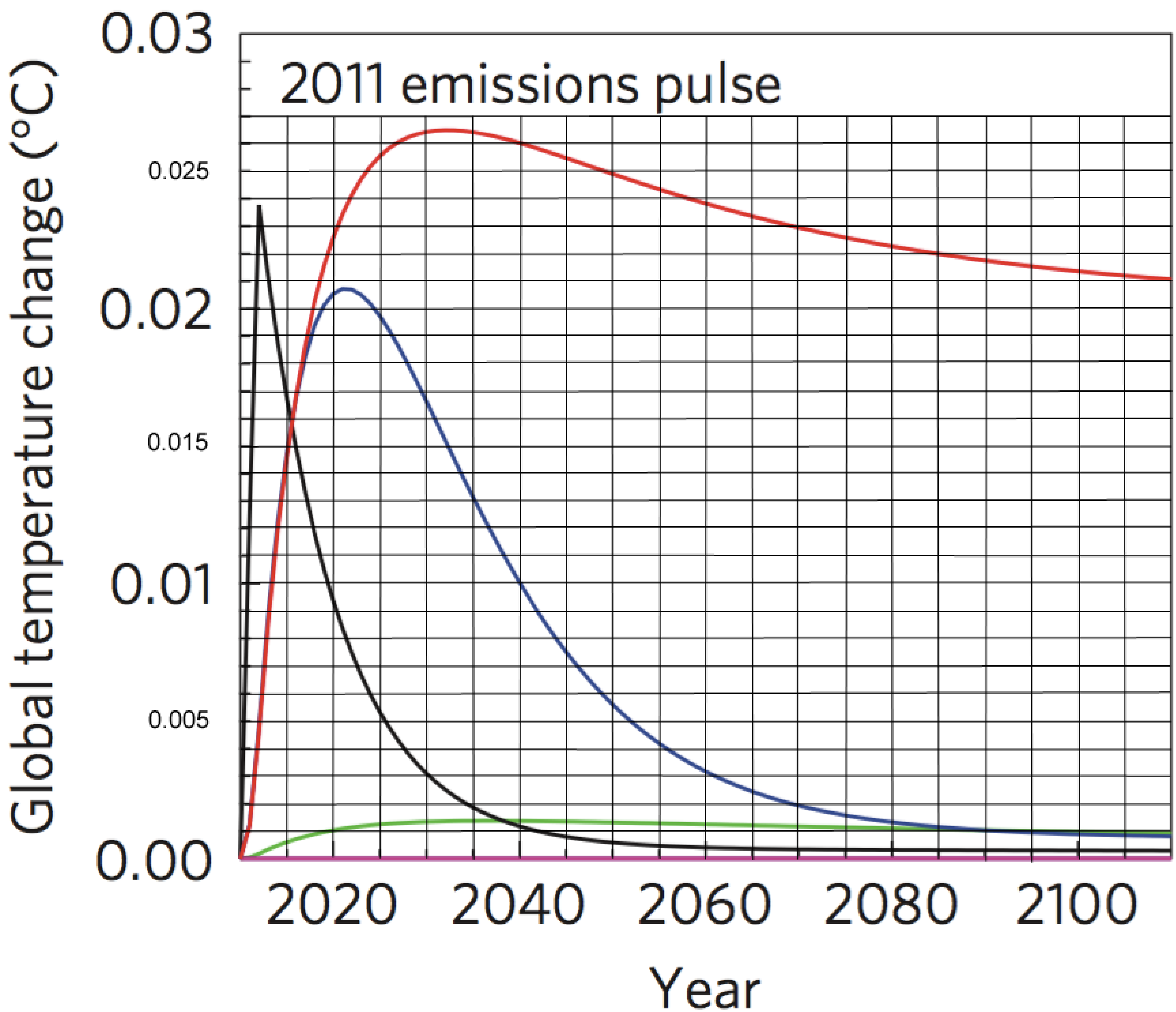
Sources: *The last frontiers of wilderness: Tracking loss of intact forest landscapes from 2000 to 2013.* Potapov et al. Sci. Adv. 2017; 3: e1600821 13 January 2017, Pages 2,6,7; see Aragao et al. (2014) above.

[Note: Annual global carbon sequestration by intact primary forest landscapes in 2014 would have been (375.5 MMT plus 289.455 MMT plus 1,150.767 MMT plus 266.745MMT) less than in 1965.]

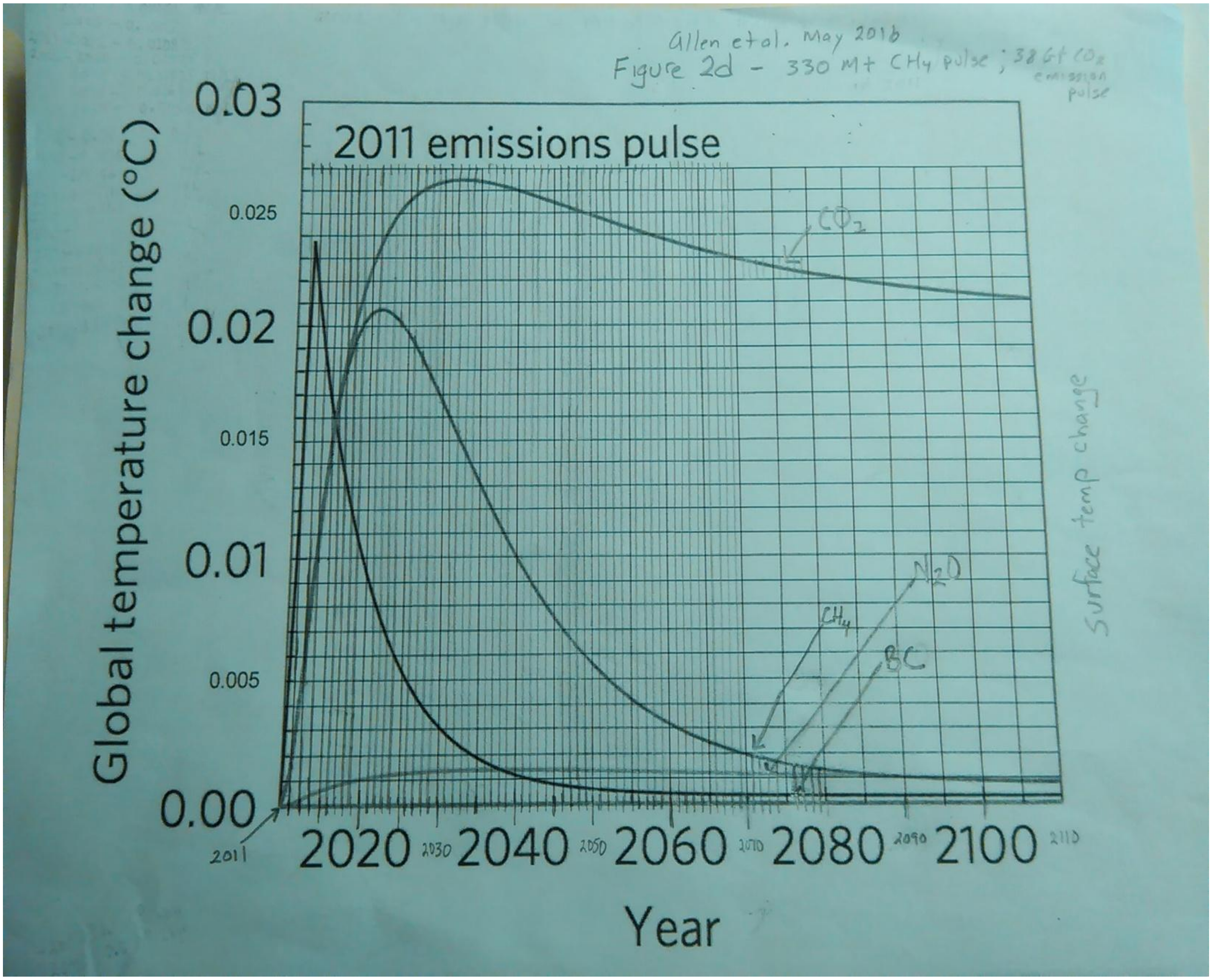
Appendix C: Table 2d from Allen et al. (2016), With and Without Grid Superimposed



[redacted] - Figure 2 - Impact of actual 2011 emissions of each climate forcing agent as a pulse: CO_2 - 38 Gt - antropogenic; CH_4 - 330 Mt (allen et al, 2016)



2011 emissions pulse
0.03
0.025
0.02
0.015
0.01
0.005
0.00
Global temperature change (°C)
2020
2040
2060
2080
2100
Year



Allen et al. May 2016
Figure 2d - 330 Mt CH4 pulse; 38 Gt CO2 emission pulse
2011 emissions pulse
Global temperature change (°C)
0.03
0.025
0.02
0.015
0.01
0.005
0.00
2011
2020
2030
2040
2050
2060
2070
2080
2090
2100
2110
Year
CO2
CH4
N2O
BC
Surface temp change

2011 - 330 mt #2 - accurate (generally more than #1)

Yr	Temp Δ in °C	Yr	Temp Δ in °C	Yr	Temp Δ in °C
2012	0.00150	2046	0.00700	2080	0.00128
2013	0.00500	2047	0.00666	2081	0.00123
2014	0.01000	2048	0.00625	2082	0.00118
2015	0.01450	2049	0.00595	2083	0.00113
2016	0.01633	2050	0.005666	2084	0.00108
2017	0.01800	2051	0.005333	2085	0.00104
2018	0.01920	2052	0.005000	2086	0.00103
2019	0.02000	2053	0.004750	2087	0.00102
2020	0.02050	2054	0.00440	2088	0.00101
2021	0.02075	2055	0.004166	2089	0.00100
2022	0.02066	2056	0.004000	2090	0.00100
2023	0.02040	2057	0.00380		
2024	0.020166	2058	0.00350		
2025	0.01975	2059	0.00325		
2026	0.019166	2060	0.003166		
2027	0.018500	2061	0.00300		
2028	0.017900	2062	0.00280		
2029	0.01725	2063	0.00260		
2030	0.01666	2064	0.00250		
2031	0.01600	2065	0.00240		
2032	0.01525	2066	0.00230		
2033	0.01450	2067	0.00220		
2034	0.01380	2068	0.00211		
2035	0.01300	2069	0.00203		
2036	0.01250	2070	0.00195		
2037	0.01190	2071	0.00187		
2038	0.01120	2072	0.00179		
2039	0.01050	2073	0.00171		
2040	0.01000	2074	0.00163		
2041	0.00950	2075	0.00157		
2042	0.00900	2076	0.00151		
2043	0.00850	2077	0.00145		
2044	0.00800	2078	0.00139		
2045	0.00750	2079	0.00133		

2013-2052 - 0.005°

2014-2040 - 0.010°

CO_2 38 Gt 2011 Emission Pulse

Yr	Temp Δ in °C	Yr	Year Δ in °C	Yr	Temp Δ in °C
2012	0.00150	2046	0.02533	2080	0.02215
2013	0.00500	2047	0.02520	2081	0.02212
2014	0.01000	2048	0.02510	2082	0.02209
2015	0.01450	2049	0.02500	2083	0.02206
2016	0.01633	2050	0.02490	2084	0.02203
2017	0.01800	2051	0.02485	2085	0.02200
2018	0.02025	2052	0.02480	2086	0.02197
2019	0.02166	2053	0.02466	2087	0.02194
2020	0.02275	2054	0.02440	2088	0.02191
2021	0.02360	2055	0.02425	2089	0.02188
2022	0.02420	2056	0.02415	2090	0.02185
2023	0.02490	2057	0.02405	2091	0.02181
2024	0.025166	2058	0.02400	2092	0.02177
2025	0.02560	2059	0.02395	2093	0.02174
2026	0.02585	2060	0.02385	2094	0.02170
2027	0.02610	2061	0.02375	2095	0.02166
2028	0.02625	2062	0.02370	2096	0.02160
2029	0.02633	2063	0.02366	2097	0.02154
2030	0.02640	2064	0.02350	2098	0.02148
2031	0.02650	2065	0.02333	2099	0.02140
2032	0.02650	2066	0.02325	2100	0.02133
2033	0.02650	2067	0.02315	2101	0.02128
2034	0.02645	2068	0.02305	2102	0.02123
2035	0.02640	2069	0.02300	2103	0.02120
2036	0.02633	2070	0.02295	2104	0.02117
2037	0.02625	2071	0.02290	2105	0.02115
2038	0.02615	2072	0.02285	2106	0.02112
2039	0.02610	2073	0.02280	2107	0.02109
2040	0.02600	2074	0.02275	2108	0.02106
2041	0.02590	2075	0.02266	2109	0.02103
2042	0.02580	2076	0.02255	2110	0.02100
2043	0.02570	2077	0.02245		
2044	0.02560	2078	0.02233		
2045	0.02550	2079	0.02220		

Bibliography

Allen, Myles R., Jan S. Fuglestvedt, Keith P. Shine, Andy Reisinger, Raymond T. Pierrehumbert, and Piers M. Forster. 2016. “New Use of Global Warming Potentials to Compare Cumulative and Short-lived Climate Pollutants,” N*ature Climate Change*, Figure 2d, http://www.nature.com/nclimate/journal/v6/n8/full/nclimate2998.html (accessed March 5, 2017).

Aragao, Luiz E. O. C., Benjamin Poulter, Jos B. Barlow, Liana O. Anderson, Yadvinder Malhi, Sassan Saatchi, Oliver L. Phillips, and Emanuel Gloors. 2014. “Environmental Change and the Carbon Balance of Amazonian Forests.” *Biol Rev* 89:913–931. doi:10.1111/brv.12088.

Boden, T.A., G. Marland, and R.J. Andres. 2016. *Global, Regional, and National Fossil-Fuel CO_2 Emissions*. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, TN, USA. doi 10.3334/CDIAC/00001_V2016, http://cdiac.ornl.gov/trends/emis/tre_glob_2013.html (accessed March 5, 2017).

Ciais, P., C. Sabine, G. Bala, L. Bopp, V. Brovkin, J. Canadell, A. Chhabra, R. DeFries, J. Galloway, M. Heimann, C. Jones, C. Le Quéré, R.B. Myneni, S. Piao and P. Thornton, 2013: Carbon and Other Biogeochemical Cycles. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [**IPCC**]* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

FAO. 2006. *Cattle Ranching and Deforestation*. Livestock Policy Brief No. 3 Animal Production and Health Division. Rome, 2.

Gerber, P.J., H. Steinfeld, B. Henderson, A. Mottet, C. Opio, J. Dijkman, A. Falcucci and G. Tempio. 2013. *Tackling Climate Change through Livestock—A global Assessment of Emissions and Mitigation Opportunities*. Rome: Food and Agriculture Organization of the United Nations (FAO), 15.

Goodland, R. and J. Anhang. 2009. "Livestock and Climate Change," *World Watch Magazine*, Nov/Dec, 22(6): 11, 13.

Myers, Norman, *Conversion of Tropical Moist Forests*, Myers, N. (1980), Pages 44,123,124; Committee on Research Priorities in Tropical Biology; National Research Council, pages 44 and 46, http://www.nap.edu/catalog.php?record_id=19767.

Myhre, G. et al. in *Climate Change 2013: The Physical Science Basis* (eds Stocker, T. F. et al.) Ch. 8 and Ch. 6 (**IPCC**, Cambridge Univ. Press, 2013).

Opio, C., P. Gerber, A. Mottet, A. Falcucci, G. Tempio, M. MacLeod, T. Vellinga, B. Henderson, and H. Steinfeld. 2013. *Greenhouse Gas Emissions from Ruminant Supply Chains—A Global Life Cycle Assessment*. Food and Agriculture Organization of the United Nations (FAO), Rome.

Peters, Glen. P., Robbie M. Andrew, Tom Boden, Josep G. Canadell, Philippe Ciais, Corinne Le Quéré, Gregg Marland, Michael R. Raupach, and Charlie Wilson. 2013. “The Challenge to Keep Global Warming Below 2°C.” *Nature Clim. Change* 3:4–6, http://www.nature.com/nclimate/journal/v3/n1/full/nclimate1783.html (accessed March 5, 2017).

Pierrehumbert, R.T. 2014. “Short-Lived Climate Pollution”, *Annu. Rev. Earth Planet. Sci*. 42:374–75.

Potapov, Peter, Matthew C. Hansen, Lars Laestadius, Svetlana Turubanova, Alexey Yaroshenko, Christoph Thies, Wynet Smith, Ilona Zhuravleva, Anna Komarova, Susan Minnemeyer, and Elena Esipova. 2017. “The last frontiers of wilderness: Tracking loss of intact forest landscapes from 2000 to 2013.” *Science Advances* 3(1), e1600821 DOI: 10.1126/sciadv.1600821, 2, 6–7.