Predicting International Carbon Dioxide and Greenhouse Gas Emission Levels with Dynamic Mode Decomposition

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Project Goal

- Use Dynamic Mode Decomposition (DMD) for two parts of the United Nations' International Greenhouse Gas (GHG) Inventory Data [7]
- First data section: Annual carbon dioxide (CO2) emissions from 1990-2014 [7]
- Second data section: Annual GHG emissions from 1990-2014 [7]

Key Questions

- Can DMD accurately predict CO2 and GHG emissions after 2014?
- How will DMD results compare to the original data set?
- Will DMD give similar types of predictions for CO2 emissions and GHG emissions?

Why This Topic?

- GHG is the main culprit behind climate change and CO2 is the largest contributor to GHG emissions [2]
- Global mean surface air temperature went up an estimated 1.53 degrees Fahrenheit from 1880-2012 [2]
- Increased global average temperature heightens the risk of floods and droughts, increases sea level, strengthens hurricanes, and leads to the extinction of numerous species [2]
- Estimates on future global average temperature depend on future GHG emission levels [2]

Other Work Using DMD

- Using a variation of DMD with measurements on the upstream velocity of a wind turbine to accurately predict the upstream velocity at an unmeasured position [1]
- Mapping out data sets like flu trends in the United States, pre-vaccinated measles cases in the United Kingdom, and type 1 polio cases in Nigeria [5]
- Potentially working with stock market trends if paired with a learning algorithm to improve sampling and prediction windows [3]
- Predicting the next few hours to weeks of demand for electricity [4]

What is DMD?

- DMD is a mathematical tool that relies on measurements from different points in time and is considered equation-free [5]
- DMD does not try solving for a set of equations that directly calculate the entire data set [5]
- DMD instead approximates a nonlinear data set into a linear model
- The linear model estimates near-future states of the data set [3]
- DMD uses dimension reduction [3]
- DMD can be used for reconstruction like recovering data with measurement or signal gaps [6]

Preparing a Data Set for DMD

- The CO2 data set is organized into two matrices:

$$X = [\bar{x}_1, \bar{x}_2, \bar{x}_3, ...\bar{x}_{m-1}] \tag{1}$$

$$\bar{X} = [\bar{x}_2, \bar{x}_3, \bar{x}_4, ...\bar{x}_m] \tag{2}$$

- Each entry in X and $\bar{X}$ is a column listing all of the CO2 values for a year in each country or region in the data set
- Each column in X corresponds to a year from 1990-2013 and each column in $\bar{X}$ corresponds to a year from 1991-2014
- Two more matrices are created the same way for the GHG data set called Y and $\bar{Y}$

Sample of the Data Set in X

- A small section of X looks like this without the location / year labels
- $\bar{X}$ has the same structure but with data from 1991-2014

Location / Year	1990	1991	1992	...	2013
Australia	278266	279742	284766	...	396914
Austria	62297	65904	60432	...	67957
Belarus	100438	93649	87061	...	61511
⋮	⋮	⋮	⋮	...	⋮
United States	5115095	5064880	5170274	...	5502551

Table 1: Annual CO2 emissions emissions in each location (rounded to the nearest integer) - Data set from [7]

What Results From DMD?

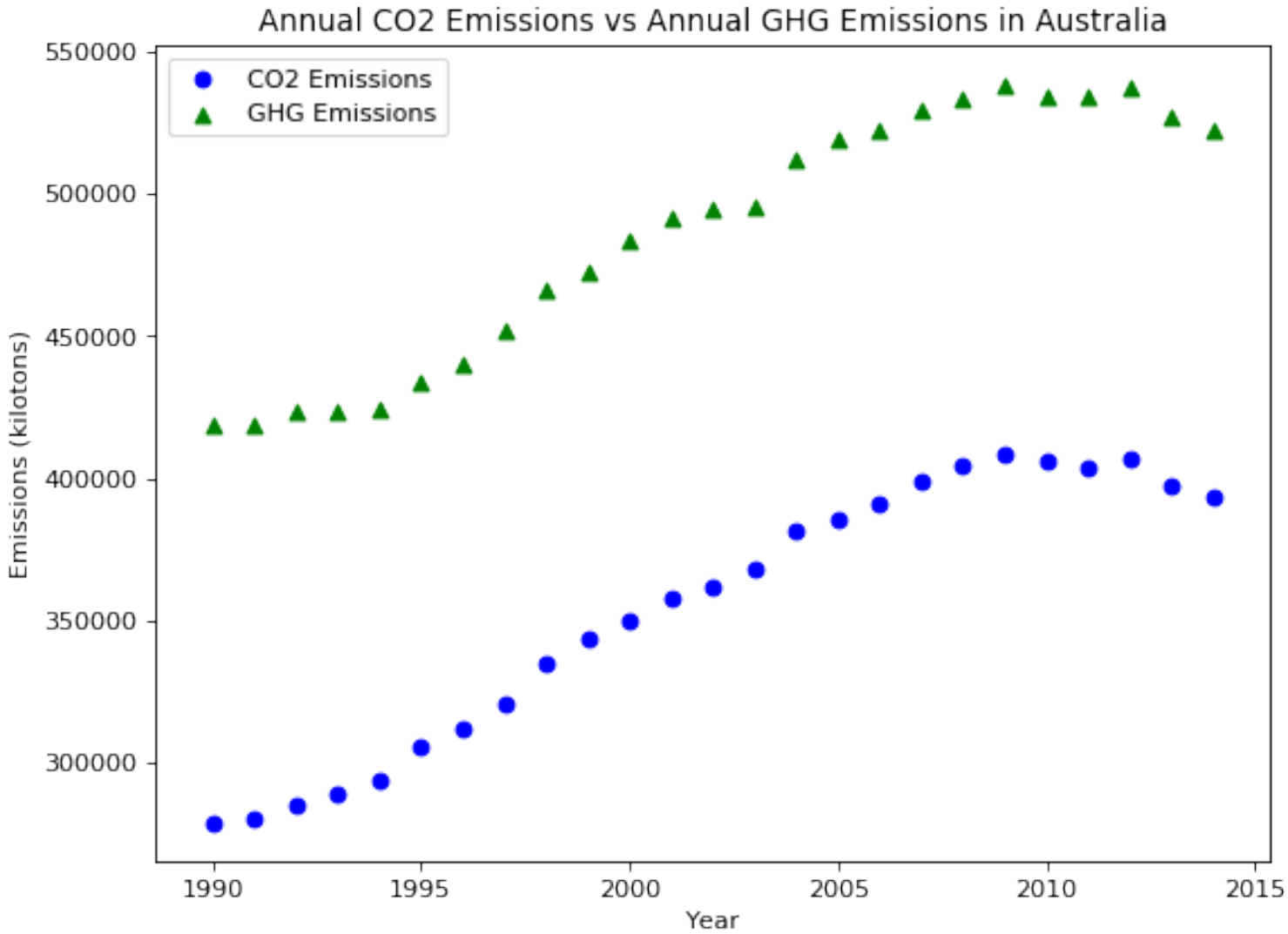
- Depending on the method used for DMD (discrete or continuous), the result for the CO2 data set is in terms of x_k or $\vec{x}(t)$
- x_k or $\vec{x}(t)$ is a column vector where each entry corresponds to the CO2 emission levels of a country or area in the data set during year k or year t
- k or $t = 0$ corresponds to the year 1990 - The first entry of x_0 corresponds to the CO2 emission levels of Australia in 1990
- k or $t = 25$ corresponds to the year 2015, so x_{25} is an estimate of the CO2 emission levels in every country or region in the data set during the year 2015
- GHG DMD results use the same structure except with y instead of x

More Info on Data Set

- The data set is arranged by country or area in alphabetical order, by year in reverse-chronological order, and by emission type (CO2 and GHG are measured in kilotons)
- The data set also includes sections for measuring other gases like methane and nitrous oxide
- The full list of countries or areas with CO2 and GHG values from 1990-2014 is below:
- Australia (1), Austria (2), Belarus (3), Belgium (4), Canada (5), Croatia (6), Cyprus (7), Czech Republic (8), Denmark (9), Estonia (10), the European Union (11), Finland (12), France (13), Germany (14), Greece (15), Hungary (16), Iceland (17), Ireland (18), Italy (19), Japan (20), Latvia (21), Lithuania (22), Malta (23), Netherlands (24), New Zealand (25), Norway (26), Poland (27), Portugal (28), Romania (29), Russian Federation (30), Slovakia (31), Slovenia (32), Sweden (33), Switzerland (34), Turkey (35), Ukraine (36), United States (37)

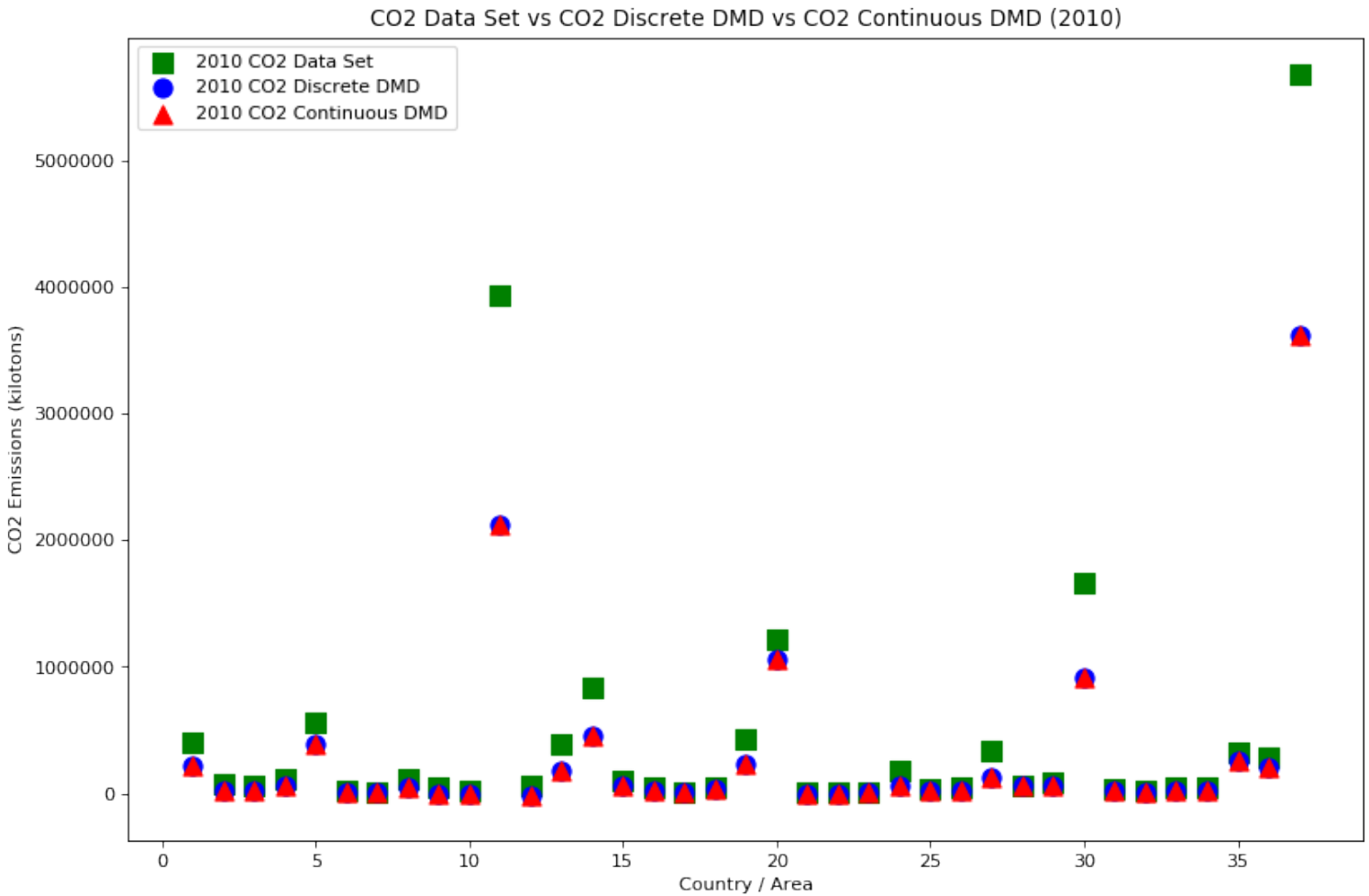
Sample Plot From Data Set

- This contains all of Australia's CO2 and GHG emission data [7]



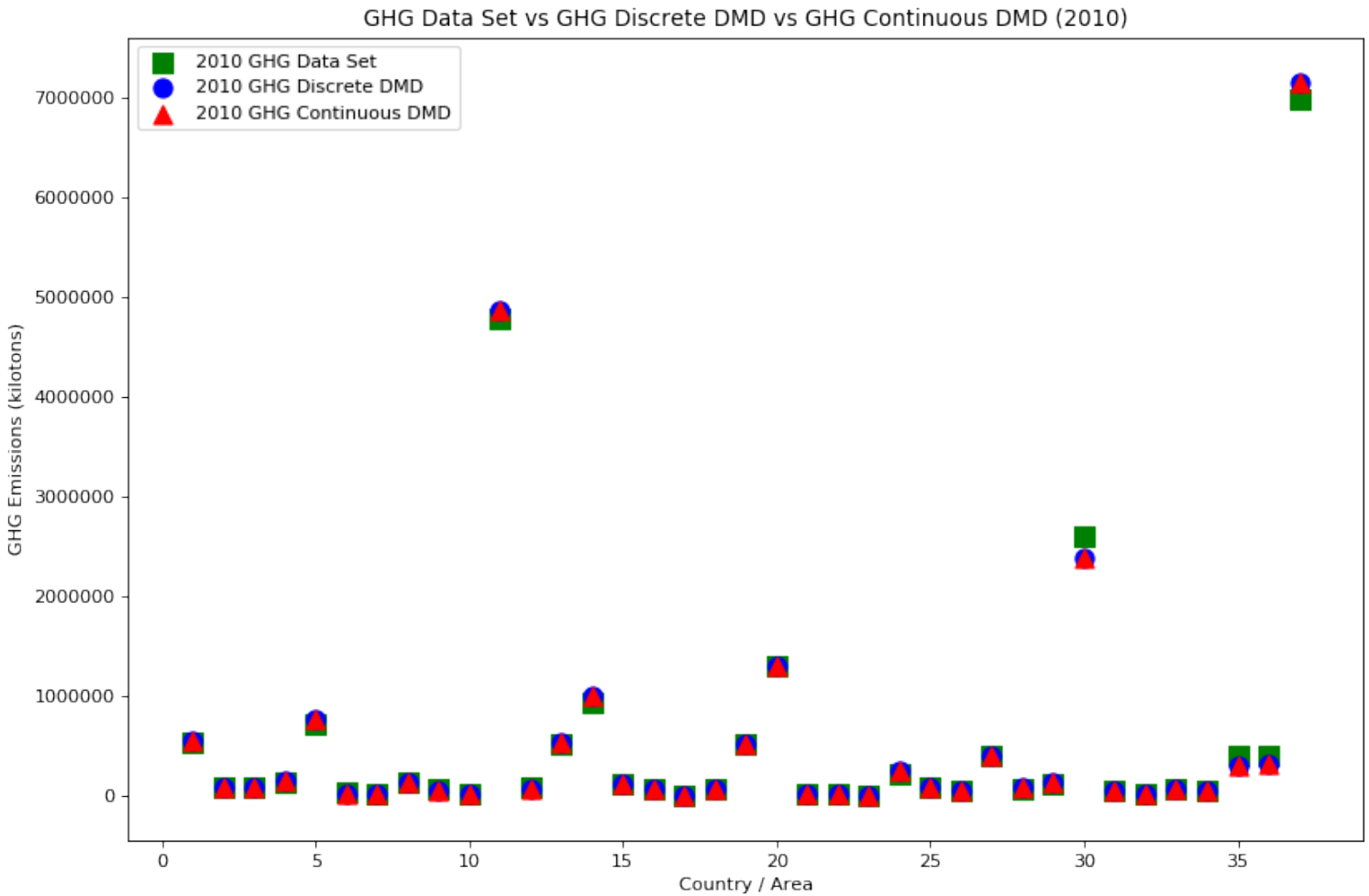
Data Set vs Discrete DMD vs Continuous DMD (2010 CO2)

- Each x-axis number refers to a country or area in the data set



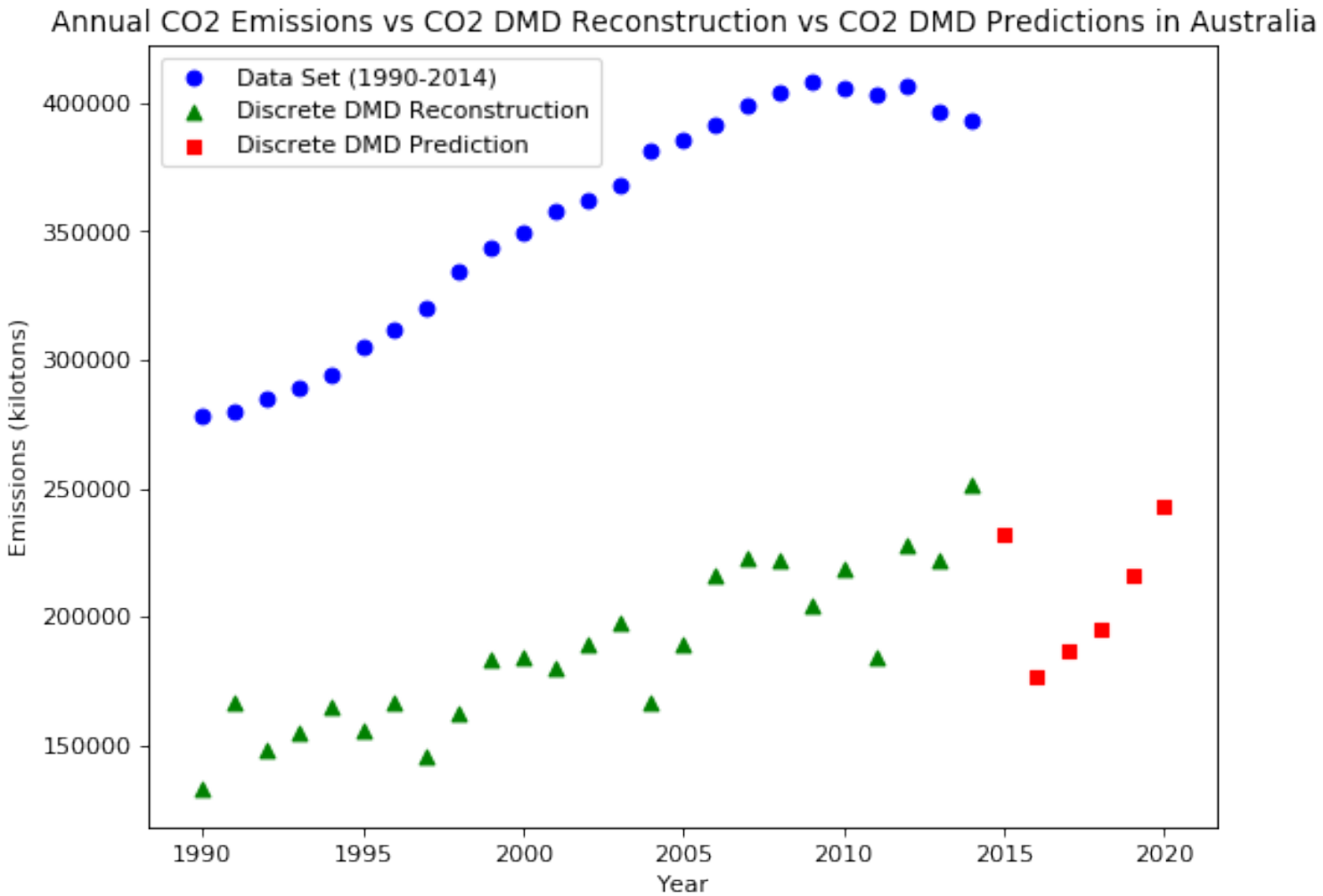
Data Set vs Discrete DMD vs Continuous DMD (2010 GHG)

- Each x-axis number refers to a country or area in the data set



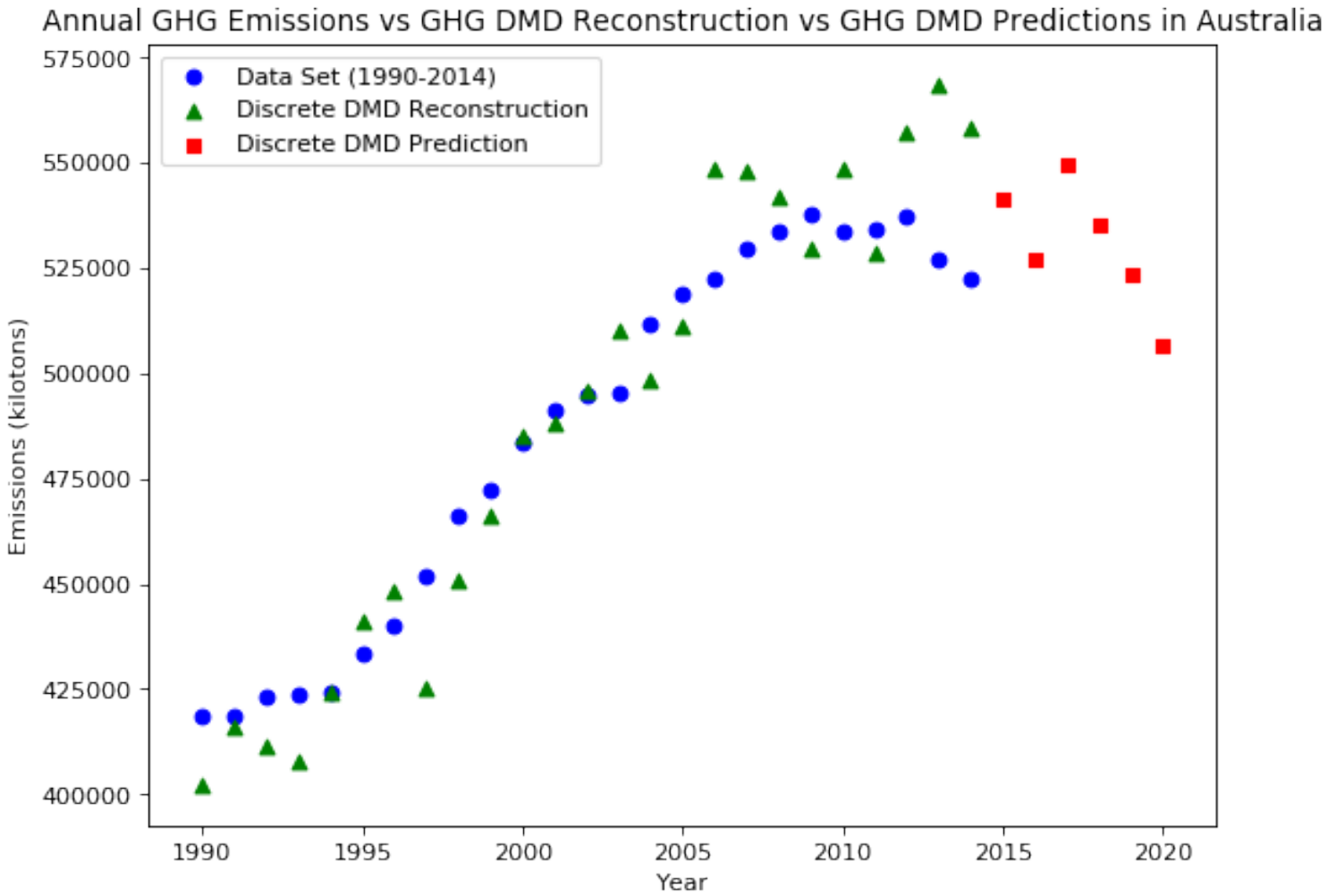
Data Set vs Discrete DMD (Australia CO2)

- Data set from [7]



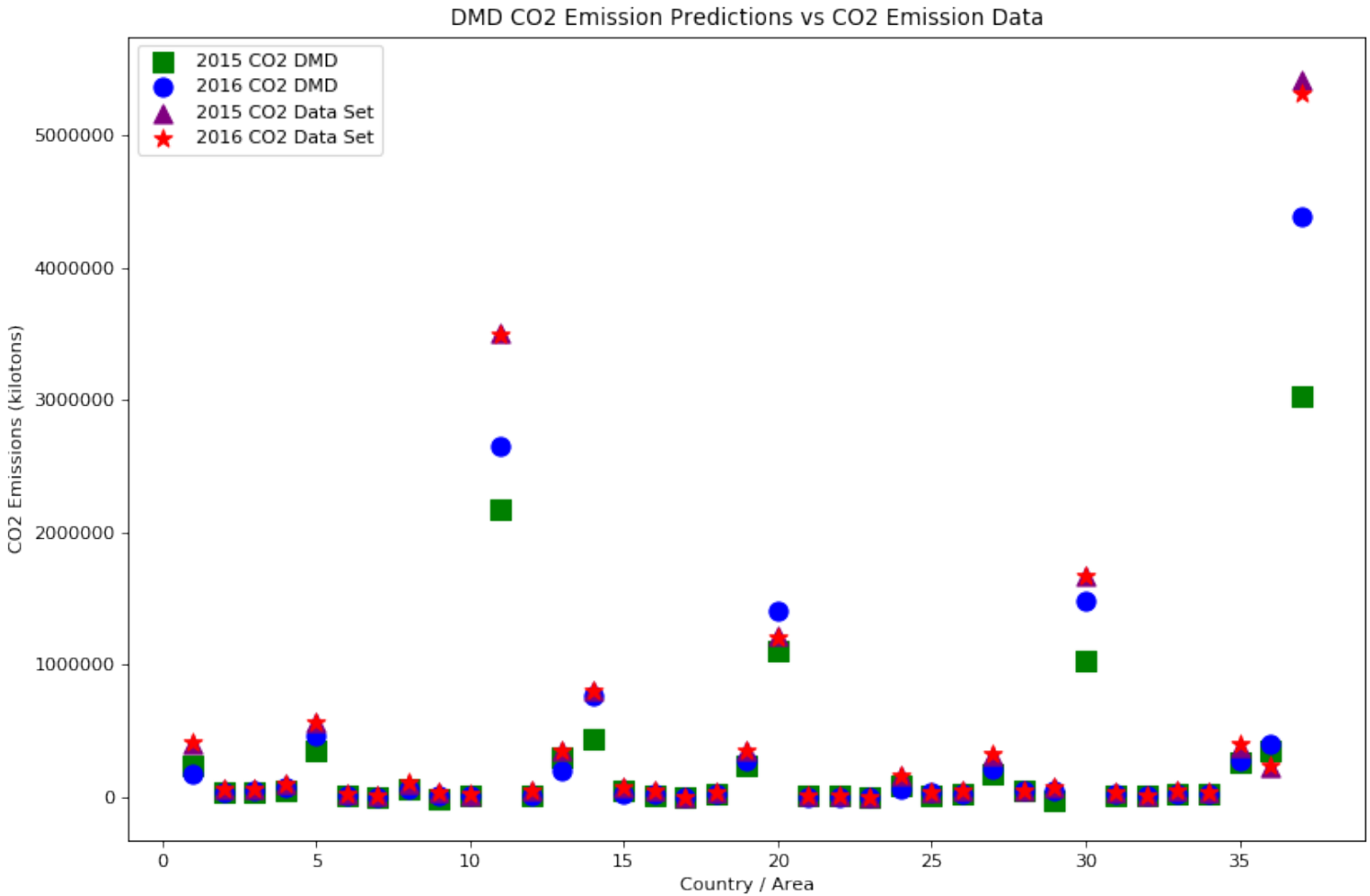
Data Set vs Discrete DMD (Australia GHG)

- Data set from [7]



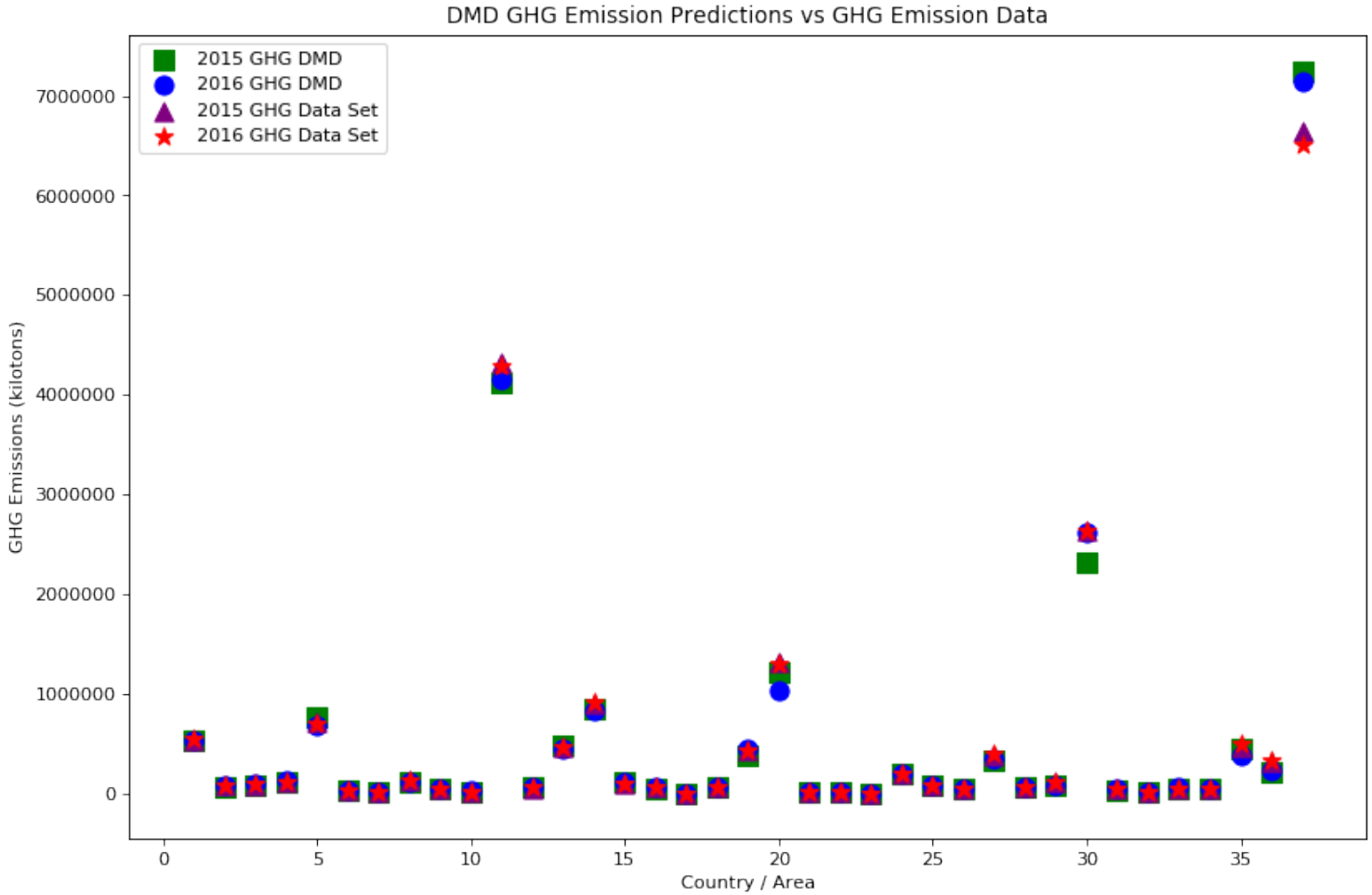
CO2 Emission Predictions vs CO2 Emission Data

- 2015 and 2016 CO2 DMD predictions vs 2015 and 2016 CO2 DMD data [8]



GHG Emission Predictions vs GHG Emission Data

- 2015 and 2016 GHG DMD predictions vs 2015 and 2016 GHG data [9] - Note: DMD model includes indirect CO2 while the 2015 and 2016 data does not include indirect CO2



Interpretation of Results

- The CO2 and GHG DMD models show similar trends in their results
- The GHG DMD models are consistently more accurate than the CO2 DMD models - Why?
- Perhaps differences in the CO2 and GHG data sets

Discussion

- Programming for DMD was a bit more straightforward than expected
- Preparing the data set for DMD to create X, $\bar{X}$, Y, and $\bar{Y}$ took longer than expected
- This might be the first project to attempt predicting CO2 and GHG emission levels by using DMD on an international data set
- DMD showed mixed results for predicting CO2 emission levels but very strong results for predicting GHG emission levels
- The DMD trend results for CO2 and GHG emission levels appeared consistent overall

References I

Thanks for listening! Any questions?

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[1] Clainche, S.L., Lorente, L.S., & Vega, J.M. (2018). Wind predictions upstream wind turbines from a LiDAR database. *Energies, 11*(4), 543. Retrieved from: `https://www.mdpi.com/1996-1073/11/3/543`

[2] Henson, R. (2014). *The thinking person's guide to climate change*. Boston: American Meteorological Society.

[3] Mann, J., & Kutz, J.N. (2015). Dynamic mode decomposition for financial trading strategies. *Quantitative Finance, 16*(11). doi: 10.1080/14697688.2016.1170194

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[4] Mohan, N., Soman, K.P., & Sachin Kumar, S. (2018). A data-driven strategy for short-term electric load forecasting using dynamic mode decomposition model. *Applied Energy, 232*, 229-244. Retrieved from: https://doi.org/10.1016/j.apenergy.2018.09.190

[5] Proctor, J.L., & Eckhoff, P.A. (2015). Discovering dynamic patterns from infectious
disease data using dynamic mode decomposition. *International Health, 7*(2), 139-145. doi: 10.1093/inthealth/ihv009

[6] Schmid, P.J. (2011). Application of the dynamic mode decomposition to experimental data. *Experiments in Fluids, 50*(4), 1123-1130. doi: 10.1007/s00348-010-0911-3

References III

[7] United Nations (2017). International Greenhouse Gas Emissions: A global GHG inventory from 1990-2017. Retrieved from: https://www.kaggle.com/unitednations/international-greenhouse-gas-emissions

[8] United Nations (2019). Carbon dioxide (CO2) Emissions without Land Use, Land-Use Change and Forestry (LULUCF), in kilotonne CO2 equivalent. Retrieved from: http://data.un.org/Explorer.aspx

[9] United Nations (2019). Greenhouse Gas (GHGs) Emissions without Land Use, Land-Use Change and Forestry (LULUCF), in kilotonne CO2 equivalent. Retrieved from: http://data.un.org/Explorer.aspx