

Covid-19 Time Series Modeling

- Flex
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[\(https://datascienceprojectsandmore.blogspot.com/\)](https://datascienceprojectsandmore.blogspot.com/)
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Abstract

This project creates a model that forecasts the number of deaths by Covid-19 given the historical data. The Covid-19 pandemic was detrimental in the number of people who perished from this disease. The idea behind this project is that if we can create a predictive model that will forecast the amount of harm, then public health officials can be better informed, advised, and empowered to mitigate future deaths. Specifically, this project focuses on a continent-wide evaluation, looking at Asia.

This project goes through a model iteration process, starting with a naive time series model, and iterating through ARIMA, multivariate ARIMA, Linear Regression, Facebook's Prophet, and multivariate prophet models. The project finalizes on the multivariate prophet model as the final model based on the evaluation metric, root mean squared error, and evaluates this model on the holdout test set. Lastly, the project offers a few recommendations to the proposed business and next steps for future projects.

- [GitHub README \(\)](#)
- [non-technical presentation \(\)](#)

Introduction

The Covid-19 Pandemic



The Covid-19 pandemic needs little introduction as it left no corner of our world untouched. It devastated lives, and economies -- day-to-day life was dramatically altered for about 2-3 years. During the pandemic, the World Health Organization, along with many other public health entities, concerned themselves with not only reacting to this public health crisis but also to recording and analyzing the data from the outbreak. This data accumulation was not only a way to evaluate the devastation and how different countries handled the situation, but also to allow them to provide better recommendations and make impactful decisions concerning public health.

This Project | The Business + Business Problem

The specific business for this project is one akin to the World Health Organization (WHO) that 'treats data as a public good' ([WHO Principles](https://data.who.int/about/data/who-data-principles) (<https://data.who.int/about/data/who-data-principles>)), and also wants to leverage this data to make recommendations to public health officials. When the pandemic arose, the WHO aided in the response including "facilitating research, developing guidance, coordinating vaccine development and distribution, and monitoring daily case numbers and trends around the world" ([WHO_COVID-19](https://www.who.int/news-room/fact-sheets/detail/coronavirus-disease-(covid-19)) ([https://www.who.int/news-room/fact-sheets/detail/coronavirus-disease-\(covid-19\)](https://www.who.int/news-room/fact-sheets/detail/coronavirus-disease-(covid-19)))). Another company, Our World in Data, has extensive documentation of the Covid-19 pandemic ([Our World in Data/coronavirus](https://ourworldindata.org/coronavirus) (<https://ourworldindata.org/coronavirus>)).

The idea for this project is to create a model that will forecast how much worse the pandemic will be in order to advise public health officials and policy makers on how to best handle the situation such that damages are minimized. We will use the number of deaths as the target to forecast and evaluate how harmful the outbreak is (or will be for predictions).

The Data Source

The Data from this project is sourced directly from Kaggle, a dataset called [Our World in Data - COVID-19](https://www.kaggle.com/datasets/caesarmario/our-world-in-data-covid19-dataset) (<https://www.kaggle.com/datasets/caesarmario/our-world-in-data-covid19-dataset>). The company, [Our World in Data](https://ourworldindata.org/explorers/coronavirus-data-explorer) (<https://ourworldindata.org/explorers/coronavirus-data-explorer>) combined their own data along with data from the John Hopkins University and the WHO. Further details on their data and sources can be found on the [GitHub page here](https://github.com/owid/covid-19-data/blob/master/public/data/README.md) (<https://github.com/owid/covid-19-data/blob/master/public/data/README.md>).

For visual purposes, the project also utilizes a dataset of latitude and longitude data of countries from Kaggle, originally sourced from google. See that data set [here](https://www.kaggle.com/datasets/paultimothymooney/latitude-and-longitude-for-every-country-and-state) (<https://www.kaggle.com/datasets/paultimothymooney/latitude-and-longitude-for-every-country-and-state>).

Reproducing via Google CoLabs

If you are reproducing this project via Google CoLabs, please uncomment the two `!pip install` commands in the imports cell below, along with the 3 cells of code below the versions print outs. The pip install commands will allow the use of pmdarima and Prophet libraries. The three cells to uncomment will

configure the Google CoLab environment to download the data sources from Kaggle, however **be sure to enter your own Kaggle username and API**, otherwise this cell will not work. After configuring the cells download the two datasets and unzip them for further use.

In [1]: # Import Needed Libraries

```
import json
import shutil
import pandas as pd
import numpy as np
import scipy

import matplotlib.pyplot as plt
%matplotlib inline
import seaborn as sns
sns.set_style('dark')

from shapely.geometry import Point
import geopandas as gpd
from geopandas import GeoDataFrame

from sklearn.metrics import mean_squared_error
from sklearn.metrics import mean_absolute_error

from statsmodels.tsa.stattools import adfuller
from statsmodels.graphics.tsaplots import plot_acf
from statsmodels.graphics.tsaplots import plot_pacf
from statsmodels.tsa.vector_ar.var_model import VAR
from statsmodels.regression.linear_model import OLS

# For Google CoLab might need to install pmdarima and Prophet
#!pip install pmdarima
#!pip install Prophet

from pmdarima.arima import auto_arima
from prophet import Prophet
from prophet.utilities import regressor_coefficients
```

In [2]: ►

```
# Versions
import sys
import matplotlib
import sklearn
import statsmodels as sm
import prophet
import pmdarima

print('Python | ', sys.version[:5])
print('Pandas | ', pd.__version__)
print('Numpy | ', np.__version__)
print('SciPy | ', scipy.__version__)
print('Matplotlib | ', matplotlib.__version__)
print('Seaborn | ', sns.__version__)
print('Geopandas | ', gpd.__version__)
print('SciKit Learn | ', sklearn.__version__)
print('Stats Models | ', sm.__version__)
print('pmdarima | ', pmdarima.__version__)
print('Prophet | ', prophet.__version__)
```

```
Python | 3.8.5
Pandas | 1.1.3
Numpy | 1.24.4
SciPy | 1.10.1
Matplotlib | 3.3.1
Seaborn | 0.11.0
Geopandas | 0.13.2
SciKit Learn | 1.3.2
Stats Models | 0.14.1
pmdarima | 2.0.4
Prophet | 1.1.5
```

In [3]: ►

```
# Prep Google CoLab environment to download data from Kaggle
#!mkdir ~/.kaggle
#!touch ~/.kaggle/kaggle.json

#username = '' ## Your Kaggle username
#api_key = '' ## Your Kaggle API key

#api_token = {"username": username,
#             "key": api_key}

#with open('/root/.kaggle/kaggle.json', 'w') as file:
#    json.dump(api_token, file)

#!chmod 600 ~/.kaggle/kaggle.json
```

In [4]: ►

```
# Download the dataset from Kaggle
#!kaggle datasets download -d caesarmario/our-world-in-data-covid19-dataset
#!kaggle datasets download -d paultimothymooney/latitude-and-longitude-for-every-cou
```

```
In [5]: # This cell unzips the downloaded data  
#shutil.unpack_archive('our-world-in-data-covid19-dataset.zip', '/content')  
#shutil.unpack_archive('Latitude-and-Longitude-for-every-country-and-state.zip', '/c
```

Data Exploration

First, we look at the complete data and find that there are quite a few redundancies in the accumulated data. With the idea of modeling in mind, many of the columns are dropped. For example, the data includes `total_cases`, `new_cases`, `new_cases_smoothed`, `new_cases_per_million`, and `new_cases_smoothed_per_million`. For modeling, specifically for time series modeling, we are interested in the daily reports, and thus keep `new_cases_smoothed` because (a) smoothed data is better for seeing trends and (b) we want to work with the real data of the number of new cases that occurred each day. This logic is applied to many of the variables in the original data set. See below for a list of the variables kept and their definitions. See also the [GitHub page \(<https://github.com/owid/covid-19-data/blob/master/public/data/README.md>\)](https://github.com/owid/covid-19-data/blob/master/public/data/README.md) for a full list of all the variables and their descriptions.

Next, a visual of the countries in which the data is coming from is produced. The idea behind this is to try and see the best way to splice the data -- is it best by individual country, continent or by something else? After looking at this map, it is decided to break up the data by continent and focus on Asia. (*The original idea was to create models for each continent, but this project only had the bandwidth to look at one. Future work would be to expand this to the other continents and compare.*)

The project then transitions into a data cleaning phase in order to deal with the missing values in the Asia subset before looking at other 'data exploration' visuals. The reasoning behind this is we want to explore the dataset that will be used in modeling; however this needs to be created by aggregating the Asia subset such that there is only one entry per day. The missing values must be dealt with prior to aggregating. See below for further details that occur during the Data Cleaning phase.

One note concerning the data cleaning phase. A limitation of this project in specific is not only the amount of missing data in the raw data source, but also the question behind the validity of the data itself. While the WHO is a very reputable source and is to be trusted, it is widely known that countries in Asia, namely China and India, were suspected of purposefully mis-reporting deaths due to Covid-19. It is important to keep in mind that the model can only ever be as good as the data used. (see [China is 'heavily underreporting' ... \(<https://abcnews.go.com/Health/china-heavily-underreporting-number-covid-19-deaths/story?id=96389383>\)](https://abcnews.go.com/Health/china-heavily-underreporting-number-covid-19-deaths/story?id=96389383), [China deletes Covid-19 death data \(<https://www.ft.com/content/a634d844-5298-441b-b2e8-0eabe0b3c1d7>\)](https://www.ft.com/content/a634d844-5298-441b-b2e8-0eabe0b3c1d7), [WHO says China revised... \(<https://www.cnbc.com/2020/04/17/who-says-china-revised-coronavirus-infection-data-to-leave-no-case-undocumented.html>\)](https://www.cnbc.com/2020/04/17/who-says-china-revised-coronavirus-infection-data-to-leave-no-case-undocumented.html), [COVID mortality in India \(<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9836201/>\)](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9836201/), and [WHO says millions of Covid deaths... \(<https://timesofindia.indiatimes.com/india/who-says-millions-of-covid-deaths-went-unreported-in-india-centre-strongly-objects-methodology-key-points/articleshow/91349479.cms>\)](https://timesofindia.indiatimes.com/india/who-says-millions-of-covid-deaths-went-unreported-in-india-centre-strongly-objects-methodology-key-points/articleshow/91349479.cms) for further reading).

Lastly, the project goes over some visuals for the aggregated Asia subset data that will be used for modeling, including showing the target variable that will be used for the strictly time series models (as well as all the models), the number of new deaths per day.

In [6]:

```
# Look at data
df = pd.read_csv('owid-covid-data.csv')
df.info()
```

```

<class 'pandas.core.frame.DataFrame'>
RangeIndex: 350085 entries, 0 to 350084
Data columns (total 67 columns):
 #   Column           Non-Null Count Dtype
 ---  ----
 0   iso_code         350085 non-null  object
 1   continent        333420 non-null  object
 2   location          350085 non-null  object
 3   date              350085 non-null  object
 4   total_cases       312088 non-null  float64
 5   new_cases          340457 non-null  float64
 6   new_cases_smoothed 339198 non-null  float64
 7   total_deaths      290501 non-null  float64
 8   new_deaths         340511 non-null  float64
 9   new_deaths_smoothed 339281 non-null  float64
 10  total_cases_per_million 312088 non-null  float64
 11  new_cases_per_million 340457 non-null  float64
 12  new_cases_smoothed_per_million 339198 non-null  float64
 13  total_deaths_per_million 290501 non-null  float64
 14  new_deaths_per_million 340511 non-null  float64
 15  new_deaths_smoothed_per_million 339281 non-null  float64
 16  reproduction_rate    184817 non-null  float64
 17  icu_patients        37615 non-null   float64
 18  icu_patients_per_million 37615 non-null  float64
 19  hosp_patients       38902 non-null   float64
 20  hosp_patients_per_million 38902 non-null  float64
 21  weekly_icu_admissions 10205 non-null   float64
 22  weekly_icu_admissions_per_million 10205 non-null  float64
 23  weekly_hosp_admissions 23253 non-null   float64
 24  weekly_hosp_admissions_per_million 23253 non-null  float64
 25  total_tests          79387 non-null   float64
 26  new_tests            75403 non-null   float64
 27  total_tests_per_thousand 79387 non-null  float64
 28  new_tests_per_thousand 75403 non-null   float64
 29  new_tests_smoothed    103965 non-null  float64
 30  new_tests_smoothed_per_thousand 103965 non-null  float64
 31  positive_rate         95927 non-null   float64
 32  tests_per_case        94348 non-null   float64
 33  tests_units           106788 non-null  object
 34  total_vaccinations    79308 non-null   float64
 35  people_vaccinated     75911 non-null   float64
 36  people_fully_vaccinated 72575 non-null   float64
 37  total_boosters         47562 non-null   float64
 38  new_vaccinations      65346 non-null   float64
 39  new_vaccinations_smoothed 180718 non-null  float64
 40  total_vaccinations_per_hundred 79308 non-null  float64
 41  people_vaccinated_per_hundred 75911 non-null   float64
 42  people_fully_vaccinated_per_hundred 72575 non-null  float64
 43  total_boosters_per_hundred 47562 non-null   float64
 44  new_vaccinations_smoothed_per_million 180718 non-null  float64
 45  new_people_vaccinated_smoothed 180489 non-null   float64
 46  new_people_vaccinated_smoothed_per_hundred 180489 non-null  float64
 47  stringency_index       197651 non-null   float64
 48  population_density     297178 non-null   float64
 49  median_age             276367 non-null   float64
 50  aged_65_older          266708 non-null   float64
 51  aged_70_older          273597 non-null   float64
 52  gdp_per_capita         270863 non-null   float64
 53  extreme_poverty        174561 non-null   float64

```

```

54 cardiovasc_death_rate           271487 non-null float64
55 diabetes_prevalence            285303 non-null float64
56 female_smokers                 203659 non-null float64
57 male_smokers                   200889 non-null float64
58 handwashing_facilities          132973 non-null float64
59 hospital_beds_per_thousand     239669 non-null float64
60 life_expectancy                  322072 non-null float64
61 human_development_index         263138 non-null float64
62 population                      350085 non-null float64
63 excess_mortality_cumulative_absolute 12184 non-null float64
64 excess_mortality_cumulative      12184 non-null float64
65 excess_mortality                 12184 non-null float64
66 excess_mortality_cumulative_per_million 12184 non-null float64
dtypes: float64(62), object(5)
memory usage: 179.0+ MB

```

Columns	Description
continent	Continent of the geographical location
location	Geographical location
date	Date of observation
new_cases	New confirmed cases of COVID-19. Counts can include probable cases, where reported. In rare cases where our source reports a negative daily change due to a data correction, we set this metric to NA
new_cases_smoothed	New confirmed cases of COVID-19 (7-day smoothed). Counts can include probable cases, where reported.
new_deaths	New deaths attributed to COVID-19. Counts can include probable deaths, where reported. In rare cases where our source reports a negative daily change due to a data correction, we set this metric to NA.
new_deaths_smoothed	New deaths attributed to COVID-19 (7-day smoothed). Counts can include probable deaths, where reported.
reproduction_rate	Real-time estimate of the effective reproduction rate (R) of COVID-19. See https://github.com/cronondm/TrackingR/tree/main/Estimates-Database (https://github.com/cronondm/TrackingR/tree/main/Estimates-Database)
icu_patients	Number of COVID-19 patients in intensive care units (ICUs) on a given day.
hosp_patients	Number of COVID-19 patients in hospital on a given day.
new_tests	New tests for COVID-19 (only calculated for consecutive days).
new_tests_smoothed	New tests for COVID-19 (7-day smoothed). For countries that don't report testing data on a daily basis, we assume that testing changed equally on a daily basis over any periods in which no data was reported. This produces a complete series of daily figures, which is then averaged over a rolling 7-day window
positive_rate	The share of COVID-19 tests that are positive, given as a rolling 7-day average (this is the inverse of tests_per_case).
test_units	Units used by the location to report its testing data. A country file can't contain mixed units. All metrics concerning testing data use the specified test unit. Valid units are 'people tested' (number of people tested), 'tests performed' (number of tests performed. a single person can be tested more than once in a given day) and 'samples tested' (number of samples tested. In some cases, more than one sample may be required to perform a given test.)
people_vaccinated	Total number of people who received at least one vaccine dose
new_people_vaccinated_smoothed	Daily number of people receiving their first vaccine dose (7-day smoothed)
new_vaccinations	New COVID-19 vaccination doses administered (only calculated for consecutive days)

Columns	Description
new_vaccinations_smoothed	New COVID-19 vaccination doses administered (7-day smoothed). For countries that don't report vaccination data on a daily basis, we assume that vaccination changed equally on a daily basis over any periods in which no data was reported. This produces a complete series of daily figures, which is then averaged over a rolling 7-day window
total_boosters	Total number of COVID-19 vaccination booster doses administered (doses administered beyond the number prescribed by the vaccination protocol)
stringency_index	Government Response Stringency Index: composite measure based on 9 response indicators including school closures, workplace closures, and travel bans, rescaled to a value from 0 to 100 (100 = strictest response).
population_density	Number of people divided by land area, measured in square kilometers, most recent year available
median_age	Median age of the population, UN projection for 2020
aged_70_older	Share of the population that is 70 years and older in 2015
gdp_per_capita	Gross domestic product at purchasing power parity (constant 2011 international dollars), most recent year available
extreme_poverty	Share of the population living in extreme poverty, most recent year available since 2010
cardiovasc_death_rate	Death rate from cardiovascular disease in 2017 (annual number of deaths per 100,000 people)
diabetes_prevalence	Diabetes prevalence (% of population aged 20 to 79) in 2017
female_smokers	Share of women who smoke, most recent year available
male_smokers	Share of men who smoke, most recent year available
handwashing_facilities	Share of the population with basic handwashing facilities on premises, most recent year available
hospital_beds_per_thousand	Hospital beds per 1,000 people, most recent year available since 2010
life_expectancy	Life expectancy at birth in 2019
human_development_index	A composite index measuring average achievement in three basic dimensions of human development—a long and healthy life, knowledge and a decent standard of living. Values for 2019, imported from http://hdr.undp.org/en/indicators/137506 (http://hdr.undp.org/en/indicators/137506)
	Population (latest available values). See https://github.com/owid/covid-19-data/blob/master/scripts/input/un/population_latest.csv

In [7]:

```
# Choose which columns to use/drop
cols_to_use = ['continent', 'location', 'date', 'new_cases_smoothed', 'new_deaths_smoothed', 'reproduction_rate', 'icu_patients', 'hosp_patients', 'new_tests_smoothed', 'positive_rate', 'tests_units', 'people_vaccinated', 'new_people_vaccinated', 'total_boosters', 'new_vaccinations_smoothed', 'stringency_index', 'population_density', 'median_age', 'aged_70_older', 'gdp_per_capita', 'extreme_poverty', 'diabetes_prevalence', 'female_smokers', 'male_smokers', 'handwashing_facilities', 'hospital_beds_per_thousand', 'life_expectancy', 'human_development_index']
df1 = df[cols_to_use]
```

In [8]: ► df1.info()

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 350085 entries, 0 to 350084
Data columns (total 30 columns):
 #   Column           Non-Null Count  Dtype  
--- 
 0   continent        333420 non-null   object  
 1   location         350085 non-null   object  
 2   date             350085 non-null   object  
 3   new_cases_smoothed 339198 non-null   float64 
 4   new_deaths_smoothed 339281 non-null   float64 
 5   reproduction_rate 184817 non-null   float64 
 6   icu_patients      37615 non-null    float64 
 7   hosp_patients     38902 non-null    float64 
 8   new_tests_smoothed 103965 non-null   float64 
 9   positive_rate     95927 non-null    float64 
 10  tests_units       106788 non-null   object  
 11  people_vaccinated 75911 non-null    float64 
 12  new_people_vaccinated_smoothed 180489 non-null   float64 
 13  total_boosters     47562 non-null    float64 
 14  new_vaccinations_smoothed 180718 non-null   float64 
 15  stringency_index   197651 non-null    float64 
 16  population_density 297178 non-null   float64 
 17  median_age         276367 non-null   float64 
 18  aged_70_older      273597 non-null   float64 
 19  gdp_per_capita     270863 non-null   float64 
 20  extreme_poverty    174561 non-null   float64 
 21  cardiovasc_death_rate 271487 non-null   float64 
 22  diabetes_prevalence 285303 non-null   float64 
 23  female_smokers     203659 non-null   float64 
 24  male_smokers       200889 non-null   float64 
 25  handwashing_facilities 132973 non-null   float64 
 26  hospital_beds_per_thousand 239669 non-null   float64 
 27  life_expectancy    322072 non-null   float64 
 28  human_development_index 263138 non-null   float64 
 29  population         350085 non-null   float64 

dtypes: float64(26), object(4)
memory usage: 80.1+ MB
```

In [9]: ► *# Update date variable to datetime*

```
df1['date'] = pd.to_datetime(df1['date'])
```

```
<ipython-input-9-ff5bda607d92>:2: SettingWithCopyWarning:
A value is trying to be set on a copy of a slice from a DataFrame.
Try using .loc[row_indexer,col_indexer] = value instead
```

See the caveats in the documentation: https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy (https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html#returning-a-view-versus-a-copy)

```
df1['date'] = pd.to_datetime(df1['date'])
```

```
In [10]: # Import latitude & longitude data
lat_long = pd.read_csv('world_country_and_usa_states_latitude_and_longitude_values.csv')
lat_long = lat_long[['latitude', 'longitude', 'country']]
lat_long.head()
```

Out[10]:

	latitude	longitude	country
0	42.546245	1.601554	Andorra
1	23.424076	53.847818	United Arab Emirates
2	33.939110	67.709953	Afghanistan
3	17.060816	-61.796428	Antigua and Barbuda
4	18.220554	-63.068615	Anguilla

```
In [11]: # merge dataframes so can visualize
df2 = pd.merge(df1,
                lat_long,
                left_on='location',
                right_on='country',
                how='left')
```

```
In [12]: # Drop not countries
loc_to_drop = ['Africa', 'Asia', 'Europe', 'European Union', 'High income',
               'Low income', 'Lower middle income', 'North America', 'Oceania',
               'South America', 'Upper middle income', 'World']

df2 = df2[~df2['location'].isin(loc_to_drop)]
```

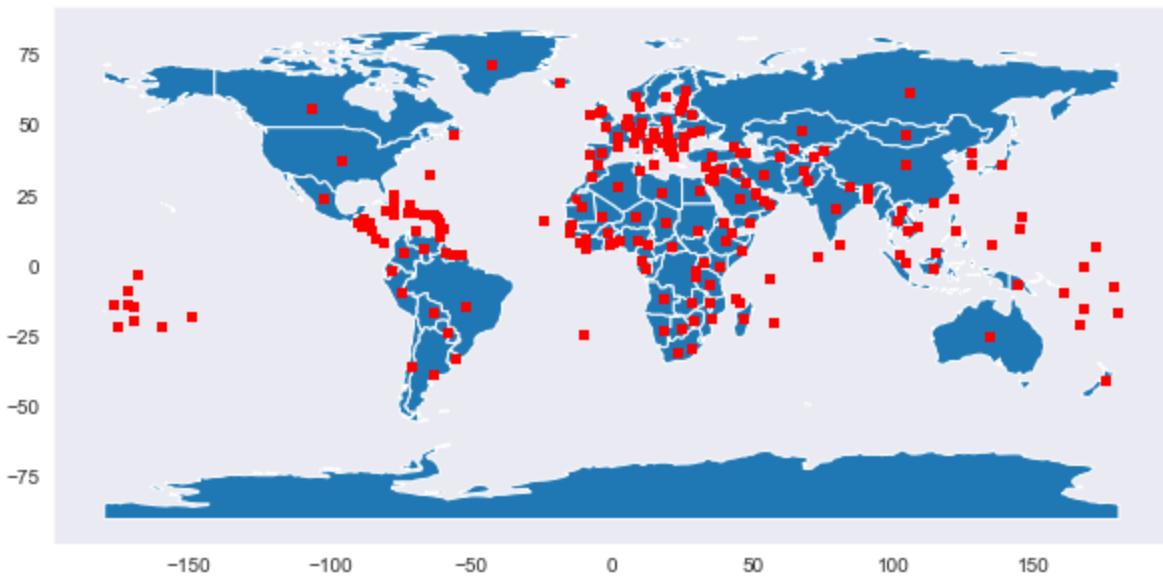
```
In [13]: # Visualize where, which countries, the data is coming from
# See https://stackoverflow.com/a/53233489 for source

geometry = [Point(xy) for xy in zip(df2['longitude'], df2['latitude'])]
gdf = GeoDataFrame(df2[['longitude', 'latitude']], geometry=geometry)

# A simple map that goes with geopandas
world = gpd.read_file(gpd.datasets.get_path('naturalearth_lowres'))
gdf.plot(ax=world.plot(figsize=(10, 6)), marker='o', color='red', markersize=15);
```

<ipython-input-13-940db7fa8124>:8: FutureWarning: The geopandas.dataset module is deprecated and will be removed in GeoPandas 1.0. You can get the original 'naturalearth_lowres' data from <https://www.naturalearthdata.com/downloads/110m-cultural-vectors/>. (<https://www.naturalearthdata.com/downloads/110m-cultural-vectors/>)

```
world = gpd.read_file(gpd.datasets.get_path('naturalearth_lowres'))
```



Based on the above graph on where the data is coming from -- the most logical and least inhibited route will be to consolidate the data by continent.

```
In [14]: # Drop non-countries from df1
df1 = df1[~df1['location'].isin(loc_to_drop)]
```

```
In [15]: # sanity check
df1['continent'].isna().sum()
```

Out[15]: 0

```
In [16]: # What are all the continents present
df1['continent'].unique()
```

Out[16]: array(['Asia', 'Europe', 'Africa', 'Oceania', 'North America',
'South America'], dtype=object)

```
In [17]: ┌ # Create the different dataframes that we will use for modeling
```

```
df_asia = df1[df1['continent'] == 'Asia']
df_eu = df1[df1['continent'] == 'Europe']
df_af = df1[df1['continent'] == 'Africa']
df_oc = df1[df1['continent'] == 'Oceania']
df_na = df1[df1['continent'] == 'North America']

df_sa = df1[df1['continent'] == 'South America']
```

```
In [18]: ┌ # Look at the total number of missing values by continent
```

```
data = [('Asia', df_asia), ('Europe', df_eu), ('Africa', df_af),
        ('Oceania', df_oc), ('North America', df_na), ('South America', df_sa)]

for (name, df) in data:
    nulls = df.isna().sum().sum()
    print(name, nulls)
```

```
Asia 610565
Europe 764416
Africa 759079
Oceania 515862
North America 792359
South America 185857
```

```
In [19]: ┌ # Visualize the countries working with in the Asia subset
```

```
df2_asia = df2[df2['continent'] == 'Asia']

geometry = [Point(xy) for xy in zip(df2_asia['longitude'], df2_asia['latitude'])]
gdf = GeoDataFrame(df2_asia[['longitude', 'latitude']], geometry=geometry)

asia = world[world['continent'] == 'Asia']
gdf.plot(ax=asia.plot(figsize=(10, 6)), marker='o', color='red', markersize=15);
```



Data Cleaning

In the below section the project handles the missing values. We first take a look at what percent of each variable is missing as well as what percent of each country is missing before looking at a visual of the number of missing values by variable by date. This, along with the context of each variable, gives us an idea of how to appropriate deal with the missing values. See below for the details

Train/Validate/Test Split?

The true train, validate, test split will occur after we aggregate the data to one row per day entry. However, we do want to keep this split in mind to avoid any unnecessary data leakage.

```
In [20]: ┌ # Look at dates where train, validate, test split will be  
unique_dates_total = len(df_asia['date'].unique())  
first_80_perc = unique_dates_total * .8  
train_end = df_asia['date'].unique()[int(first_80_perc)]  
print('Last train date:', train_end)  
  
val_perc = first_80_perc + (unique_dates_total * .1)  
val_end = df_asia['date'].unique()[int(val_perc)]  
print('Last validation date:', val_end)
```

```
Last train date: 2023-01-19T00:00:00.000000000  
Last validation date: 2023-06-07T00:00:00.000000000
```

```
In [21]: ┌ # Check percent missing by variable
  num_rows = len(df_asia['date'])
  for var in df_asia.columns:
    missing = df_asia[var].isna().sum()
    if missing > 0:
      print(var, '{}%'.format(round(missing/num_rows*100, 1)))
```

```
new_cases_smoothed 6.4%
new_deaths_smoothed 6.4%
reproduction_rate 33.9%
icu_patients 94.9%
hosp_patients 96.0%
new_tests_smoothed 61.2%
positive_rate 64.5%
tests_units 60.5%
people_vaccinated 75.0%
new_people_vaccinated_smoothed 44.4%
total_boosters 86.9%
new_vaccinations_smoothed 44.3%
stringency_index 26.4%
population_density 4.9%
median_age 1.0%
aged_70_older 1.0%
gdp_per_capita 6.9%
extreme_poverty 44.0%
cardiovasc_death_rate 4.0%
diabetes_prevalence 6.1%
female_smokers 24.0%
male_smokers 24.0%
handwashing_facilities 48.0%
hospital_beds_per_thousand 10.0%
life_expectancy 1.0%
human_development_index 6.1%
```

```
In [22]: ┌ # Check percent missing by country
  for country in df_asia['location'].unique():
    mask = df_asia['location'] == country
    num_cells = len(df_asia[mask]) * 30
    missing = df_asia[mask].isna().sum().sum()
    percent = round(missing/num_cells*100, 1)
    if percent > 40:
      print(country, '{}%'.format(percent))
```

```
Hong Kong 47.2%
Macao 58.1%
North Korea 53.2%
Northern Cyprus 80.2%
Syria 47.3%
Taiwan 54.7%
```

In [23]: # Visualize number of missing values by variable by date

```
fig, axes = plt.subplots(ncols=6, nrows=5, figsize=(20,10), sharey=True, sharex=True)

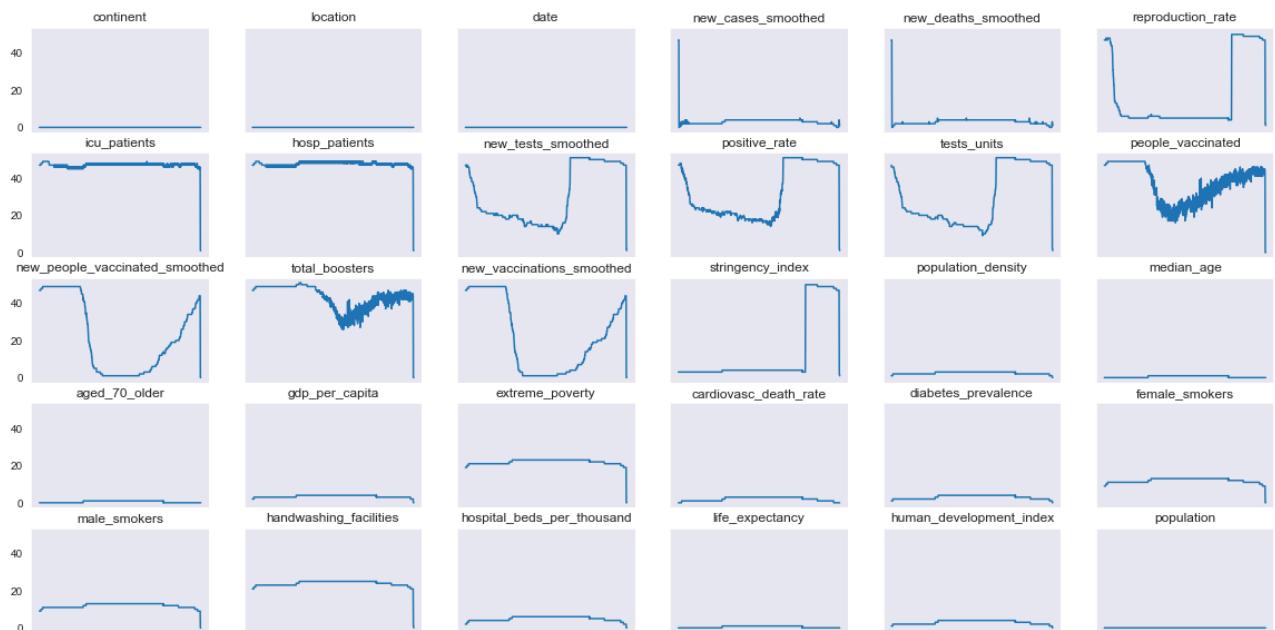
for i,var in enumerate(df_asia.columns):
    y = []
    for date in df_asia['date'].unique():
        y.append(df_asia[df_asia['date'] == date][var].isna().sum())

    row = i // 6
    col = i % 6
    ax = axes[row, col]

    ax.plot(df_asia['date'].unique(), y)
    ax.set_title(var)
    ax.set_xticks([])

plt.suptitle('Number of Nulls by Variable by Date', fontsize='xx-large');
```

Number of Nulls by Variable by Date



Based on the above information, we will move forward with:

- Dropping the below as too much data is missing:
 - Country: Northern Cyrus, Macao, and Hong Kong (while not quite 50% missing, Hong Kong is missing quite a lot and is a small regional area -- can be lumped in with China).
 - Variables: `icu_patients`, `hosp_patients`, `new_tests_smoothed`, `positive_rate`, `tests_units`, `total_boosters`,
- Furthermore Dropping:
 - `reproduction_rate` -- as the value cannot be appropriately estimated in the validation and test sets when a vast majority of the countries stopped reporting on this value.
 - `new_people_vaccinated_smoothed` -- as we will use new vaccinations smoothed instead.
- Drop the below as they will be constant for every day (thus not useful for time series modeling):
 - `population_density`, `median_age`, `aged_70_older`, `gdp_per_capita`, `extreme_poverty`, `cardiovasc_death_rate`, `diabetes_prevalence`, `female_smokers`, `male_smokers`, `handwashing_facilities`, `hospital_beds_per_thousand`, `life_expectancy`, `human_development`

In [24]:

```
# Drop countries
mask = (df_asia['location'] == 'Northern Cyprus') | (df_asia['location'] == 'Hong Ko
df_asia = df_asia[~mask]

# Drop variables
col_to_drop = ['icu_patients', 'hosp_patients', 'new_tests_smoothed', 'positive_rate
    'new_people_vaccinated_smoothed', 'total_boosters', 'extreme_poverty',
    'population_density', 'gdp_per_capita', 'diabetes_prevalence', 'female
    'hospital_beds_per_thousand', 'human_development_index']

df_asia = df_asia.drop(col_to_drop, axis=1)
```

In [25]:

```
# Recheck missing values by variable
num_rows = len(df_asia['date'])
for var in df_asia.columns:
    missing = df_asia[var].isna().sum()
    if missing > 0:
        print(var, '{}%'.format(round(missing/num_rows*100, 1)))
```

new_cases_smoothed 2.5%
new_deaths_smoothed 2.4%
people_vaccinated 76.0%
new_vaccinations_smoothed 45.6%
stringency_index 25.9%

In [26]:

```
# Recheck missing values by country
for country in df_asia['location'].unique():
    mask = df_asia['location'] == country
    num_cells = len(df_asia[mask]) * 30
    missing = df_asia[mask].isna().sum().sum()
    percent = round(missing/num_cells*100, 1)
    if percent > 20:
        print(country, '{}%'.format(percent))
```

Variable	How to Handel missing values
new_cases_smoothed	Input 0. NaN only entered when negative values present due to corrective reporting.
new_deaths_smoothed	Input 0. NaN only entered when negative values present due to corrective reporting.
people_vaccinated	Forward fill for missing values after vaccine released by country.
new_vaccinations_smoothed	Input 0. Missing values prior to vaccine release date are 0. Assume no new vaccinations or reporting error for NaN values after vaccine date.
stringency_index	By country, forward fill. Assuming a missing value means it was not reported and no change between previous assigned value. For validation & test sets with no information to forward, assume 0 value (many Covid-19 policies ended in 2023).

In [27]:

```
# Input 0 for assigned columns
# True for train, validate, and test groups -- no need to split
fill_values = {'new_cases_smoothed' : 0, 'new_deaths_smoothed':0, 'new_vaccinations_
df_asia.fillna(fill_values, inplace=True)
```

In [28]: # People Vaccinated -- Forward fill by country (start with 0)

```
# Start with 0
for country in df_asia['location'].unique():
    mask = (df_asia['location'] == country)
    mask2 = (df_asia['date'] == (df_asia.loc[mask, 'date'].unique().min()))
    mask_all = mask & mask2
    df_asia.loc[mask_all, 'people_vaccinated'] = df_asia.loc[mask, 'people_vaccinate

# Train Set
for country in df_asia['location'].unique():
    mask = (df_asia['location'] == country) & (df_asia['date'] < train_end)
    df_asia.loc[mask, 'people_vaccinated'] = df_asia.loc[mask, 'people_vaccinated']
    if df_asia.loc[mask, 'people_vaccinated'].isna().sum() > 0:
        print('train', country)

# Validation Set
for country in df_asia['location'].unique():
    mask = (df_asia['location'] == country) & (df_asia['date'] >= train_end) & (df_a
    df_asia.loc[mask, 'people_vaccinated'] = df_asia.loc[mask, 'people_vaccinated']
    if df_asia.loc[mask, 'people_vaccinated'].isna().sum() > 0:
        print('val', country)

# Test Set
for country in df_asia['location'].unique():
    mask = (df_asia['location'] == country) & (df_asia['date'] >= val_end)
    df_asia.loc[mask, 'people_vaccinated'] = df_asia.loc[mask, 'people_vaccinated']
    if df_asia.loc[mask, 'people_vaccinated'].isna().sum() > 0:
        print('test', country)
```

```
val Afghanistan
val Armenia
val Azerbaijan
val Bahrain
val Bangladesh
val Bhutan
val Brunei
val Cambodia
val Georgia
val Indonesia
val Iran
val Iraq
val Jordan
val Kazakhstan
val Kuwait
val Laos
val Lebanon
val Maldives
val Mongolia
` ..
```

Three options here:

1. Back fill from known values in Validation + Test Sets

- This would avoid any data leakage from the training set into the validation + test sets but not be quite as accurate

2. Forward fill information from train set into validation + test sets

- This would be much more accurate (this is a cumulative value per country and thus be the more accurate approach, but would mean data leakage is occurring).

3. Drop the variable

```
In [29]: # Try back filling

# Validation Set
for country in df_asia['location'].unique():
    mask = (df_asia['location'] == country) & (df_asia['date'] >= train_end) & (df_asia['date'] <= val_start)
    df_asia.loc[mask, 'people_vaccinated'] = df_asia.loc[mask, 'people_vaccinated'].bfill()
    if df_asia.loc[mask, 'people_vaccinated'].isna().sum() > 0:
        print('val', country)

# Test Set
for country in df_asia['location'].unique():
    mask = (df_asia['location'] == country) & (df_asia['date'] >= val_end)
    df_asia.loc[mask, 'people_vaccinated'] = df_asia.loc[mask, 'people_vaccinated'].bfill()
    if df_asia.loc[mask, 'people_vaccinated'].isna().sum() > 0:
        print('test', country)

val Azerbaijan
val Bahrain
val Bhutan
val Georgia
val Iraq
val Jordan
val Kazakhstan
val Laos
val Lebanon
val Mongolia
val North Korea
val Oman
val Palestine
val Sri Lanka
val Thailand
val Turkey
val United Arab Emirates
test Azerbaijan
test Bahrain
test Bangladesh
test Cambodia
test India
test Indonesia
test Iran
test Israel
test Japan
test South Korea
test Malaysia
test Pakistan
test Philippines
test Saudi Arabia
test Singapore
test Thailand
test Turkey
test United Arab Emirates
test Vietnam
```

```
In [30]: # That did not work -- rather than dropping the variable we will forward fill completely
# Yes this will mean a bit of data leakage, but it is reasonable to assume that
# people vaccinated that this number will be the same moving forward if no new records are added

for country in df_asia['location'].unique():
    mask = (df_asia['location'] == country)
    df_asia.loc[mask, 'people_vaccinated'] = df_asia.loc[mask, 'people_vaccinated'].ffill()

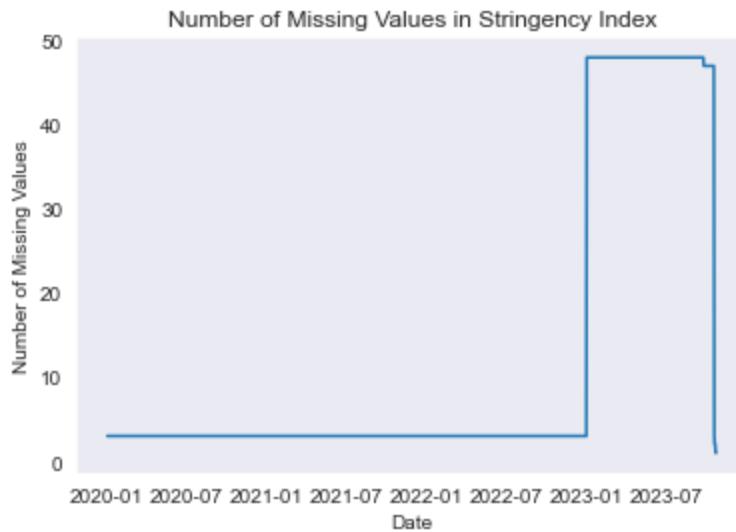
df_asia['people_vaccinated'].isna().sum()
```

Out[30]: 0

```
In [31]: # stringency_index  
df_asia['stringency_index'].isna().sum()
```

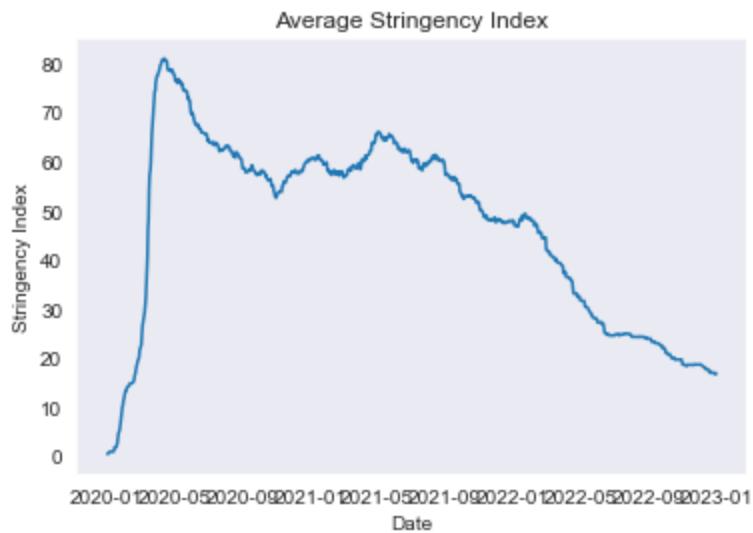
Out[31]: 17235

```
In [32]: # Look at when the missing values for stringency_index are  
y = []  
for date in df_asia['date'].unique():  
    y.append(df_asia[df_asia['date'] == date]['stringency_index'].isna().sum())  
  
fig, ax = plt.subplots()  
ax.plot(df_asia['date'].unique(), y)  
ax.set_title('Number of Missing Values in Stringency Index')  
ax.set_ylabel('Number of Missing Values')  
ax.set_xlabel('Date');
```



```
In [33]: # Look at average stringency_index by date
y = []
for date in df_asia['date'].unique():
    avg = np.mean(df_asia[df_asia['date'] == date]['stringency_index'])
    y.append(avg)

fig, ax = plt.subplots()
ax.plot(df_asia['date'].unique(), y)
ax.set_title('Average Stringency Index')
ax.set_ylabel('Stringency Index')
ax.set_xlabel('Date');
```



In [34]: # Forward Fill nulls

```
# Train Set
for country in df_asia['location'].unique():
    mask = (df_asia['location'] == country) & (df_asia['date'] < train_end)
    df_asia.loc[mask, 'stringency_index'] = df_asia.loc[mask, 'stringency_index'].ff
    if df_asia.loc[mask, 'stringency_index'].isna().sum() > 0:
        print('train', country)

# Validation Set
for country in df_asia['location'].unique():
    mask = (df_asia['location'] == country) & (df_asia['date'] >= train_end) & (df_a
    df_asia.loc[mask, 'stringency_index'] = df_asia.loc[mask, 'stringency_index'].ff
    if df_asia.loc[mask, 'stringency_index'].isna().sum() > 0:
        print('val', country)

# Test Set
for country in df_asia['location'].unique():
    mask = (df_asia['location'] == country) & (df_asia['date'] >= val_end)
    df_asia.loc[mask, 'stringency_index'] = df_asia.loc[mask, 'stringency_index'].ff
    if df_asia.loc[mask, 'stringency_index'].isna().sum() > 0:
        print('test', country)
```

train Armenia
train Maldives
train North Korea
val Afghanistan
val Armenia
val Azerbaijan
val Bahrain
val Bangladesh
val Bhutan
val Brunei
val Cambodia
val China
val Georgia
val India
val Indonesia
val Iran
val Iraq
val Israel
val Japan
...

```
In [35]: # So we have three countries where the stringency index was never reported, and, as
# most countries stopped reporting on this value starting in 2023.

# For the countries that never reported we will put the average for the day in -- the

for date in df_asia.loc[df_asia['date'] < train_end, 'date'].unique():

    if df_asia[df_asia['date'] == date]['stringency_index'].isna().sum() > 0:
        avg = np.mean(df_asia[df_asia['date'] == date]['stringency_index'])

        for country in df_asia[df_asia['stringency_index'].isna()]['location'].unique():
            mask = (df_asia['location'] == country) & (df_asia['date'] == date)
            df_asia.loc[mask, 'stringency_index'].fillna(avg)
```

For the Validation + test sets again, some options:

1. Back fill from known values in Validation + Test Sets (although as we saw above this might not work if ALL values are missing for each country.)
2. Forward fill information from train set into validation + test sets
 - This would be much more accurate (this is a cumulative value per country and thus be the more accurate approach, but would mean data leakage is occurring.)
3. Input 0 for this variable in Validation + Test Sets
 - This is reasonable only because we know that most countries dropped most if not all of their Covid-19 protections by 2023.
4. Drop the variable

In [36]: # We will try option 1 and if that fails move to option 3

```
# Try backfilling:  
# Validation Set  
for country in df_asia['location'].unique():  
    mask = (df_asia['location'] == country) & (df_asia['date'] >= train_end) & (df_a  
    df_asia.loc[mask, 'stringency_index'] = df_asia.loc[mask, 'stringency_index'].bfill()  
    if df_asia.loc[mask, 'stringency_index'].isna().sum() > 0:  
        print('val', country)  
  
# Test Set  
for country in df_asia['location'].unique():  
    mask = (df_asia['location'] == country) & (df_asia['date'] >= val_end)  
    df_asia.loc[mask, 'stringency_index'] = df_asia.loc[mask, 'stringency_index'].bfill()  
    if df_asia.loc[mask, 'stringency_index'].isna().sum() > 0:  
        print('test', country)
```

```
val Afghanistan  
val Armenia  
val Azerbaijan  
val Bahrain  
val Bangladesh  
val Bhutan  
val Brunei  
val Cambodia  
val China  
val Georgia  
val India  
val Indonesia  
val Iran  
val Iraq  
val Israel  
val Japan  
val Jordan  
val Kazakhstan  
val Kuwait  
` ..` .
```

In [37]: # Check if still nulls present

```
df_asia['stringency_index'].isna().sum()
```

Out[37]: 16425

In [38]: # That clearly did not work -- move forward with filling nulls with 0 for 2023 onward
df_asia['stringency_index'] = df_asia['stringency_index'].fillna(0)

In [39]: # Sanity Check

```
df_asia['stringency_index'].isna().sum()
```

Out[39]: 0

In [40]: # Check Total Missing Values

```
df_asia.isna().sum().sum()
```

Out[40]: 0

Aggregate Data + Explore

The next subsection aggregates the data such that there is one row per day. This will give us an overall average of Asia as a continent and allow us to make general predictions and recommendations on a larger geographical scale.

The project then goes on and looks at each variable against time, both as the aggregate value and by individual country to further comprehend what data we are working with.

```
In [41]: ┌ # Look at data
  df_asia.info()
```

```
<class 'pandas.core.frame.DataFrame'>
Int64Index: 66452 entries, 0 to 347314
Data columns (total 13 columns):
 #   Column           Non-Null Count  Dtype  
---  --  
 0   continent        66452 non-null   object  
 1   location         66452 non-null   object  
 2   date             66452 non-null   datetime64[ns]
 3   new_cases_smoothed  66452 non-null   float64 
 4   new_deaths_smoothed 66452 non-null   float64 
 5   people_vaccinated 66452 non-null   float64 
 6   new_vaccinations_smoothed 66452 non-null   float64 
 7   stringency_index    66452 non-null   float64 
 8   median_age         66452 non-null   float64 
 9   aged_70_older       66452 non-null   float64 
 10  cardiovasc_death_rate 66452 non-null   float64 
 11  life_expectancy     66452 non-null   float64 
 12  population         66452 non-null   float64 
dtypes: datetime64[ns](1), float64(10), object(2)
memory usage: 7.1+ MB
```

Variable	How to aggregate
continent	drop
location	drop
date	unique value per day
new_cases_smoothed	sum per day
new_deaths_smoothed	sum per day
people_vaccinated	sum per day (cumulative value)
new_vaccinations_smoothed	sum per day
stringency_index	average per day

```
In [42]: # Dictionary to create new data frame for time series
asia_ts_data = {}
asia_ts_data['date'] = df_asia['date'].unique()

# Average per day
avg_daily = ['stringency_index']

for var in avg_daily:
    values_to_add = []

    for date in df_asia['date'].unique():
        mask = df_asia['date'] == date
        avg = np.mean(df_asia.loc[mask, var])
        values_to_add.append(avg)

    asia_ts_data[var] = values_to_add

# Sum per day
sum_daily = ['new_cases_smoothed', 'new_deaths_smoothed', 'people_vaccinated', 'new_']

for var in sum_daily:
    values_to_add = []

    for date in df_asia['date'].unique():
        mask = df_asia['date'] == date
        sum_ = np.sum(df_asia.loc[mask, var])
        values_to_add.append(sum_)

    asia_ts_data[var] = values_to_add
```

```
In [43]: # Create new dataframe
df_asia_ts = pd.DataFrame(asia_ts_data)
df_asia_ts.set_index('date', inplace=True)
```

In [44]: ► df_asia_ts.loc['2020-12-20':'2021-01-15']

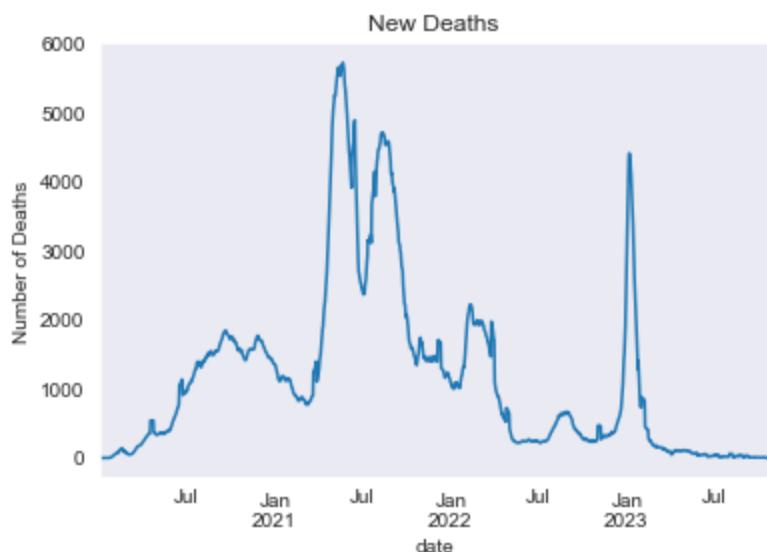
Out[44]:

date	stringency_index	new_cases_smoothed	new_deaths_smoothed	people_vaccinated	new_vaccinati
2020-12-20	55.092292	100734.858	1451.858	7468.0	
2020-12-21	55.227500	99427.855	1463.000	32391.0	
2020-12-22	55.709583	97227.430	1446.570	77060.0	
2020-12-23	55.825417	94578.716	1437.002	178942.0	
2020-12-24	55.979583	92404.430	1428.714	263483.0	
2020-12-25	56.047083	90790.141	1438.287	302473.0	
2020-12-26	56.162917	88234.286	1420.572	336104.0	
2020-12-27	56.336667	85441.143	1396.000	442739.0	
2020-12-28	56.278750	82840.140	1377.430	580902.0	
2020-12-29	56.162917	81575.859	1376.714	739920.0	
2020-12-30	56.625833	80507.140	1364.857	896610.0	
2020-12-31	56.606667	79707.714	1355.286	1058055.0	
2021-01-01	56.452500	80080.286	1357.285	1130229.0	
2021-01-02	56.597083	78588.288	1346.572	1203468.0	
2021-01-03	56.751458	77794.999	1317.714	1355459.0	
2021-01-04	56.771042	77558.857	1287.284	1510574.0	
2021-01-05	56.915833	78070.858	1250.286	1640180.0	
2021-01-06	56.761667	78557.429	1224.143	1749484.0	
2021-01-07	56.626667	79237.571	1195.716	1870329.0	
2021-01-08	56.626667	78883.282	1149.428	1943728.0	
2021-01-09	56.742292	80906.432	1137.427	1994645.0	
2021-01-10	56.742292	82562.856	1129.431	2875029.0	
2021-01-11	56.453125	83596.144	1108.287	2904063.0	

	stringency_index	new_cases_smoothed	new_deaths_smoothed	people_vaccinated	new_vaccinati
date					
2021-01-12	56.645833	83483.859	1114.855	2938502.0	
2021-01-13	56.857917	83327.285	1132.572	3000322.0	
2021-01-14	57.253542	83063.284	1157.001	3071183.0	
2021-01-15	57.253333	82873.285	1152.999	3120544.0	

In [45]:  # Look at new_deaths_smoothed -- our target variable!

```
fig, ax = plt.subplots()
df_asia_ts['new_deaths_smoothed'].plot(ax=ax)
ax.set_title('New Deaths')
ax.set_ylabel('Number of Deaths');
```



In [46]:

```
# Look at new_deaths_smoothed by country
fig, axes = plt.subplots(ncols=6, nrows=8, figsize=(15,12), sharey=True, sharex=True)

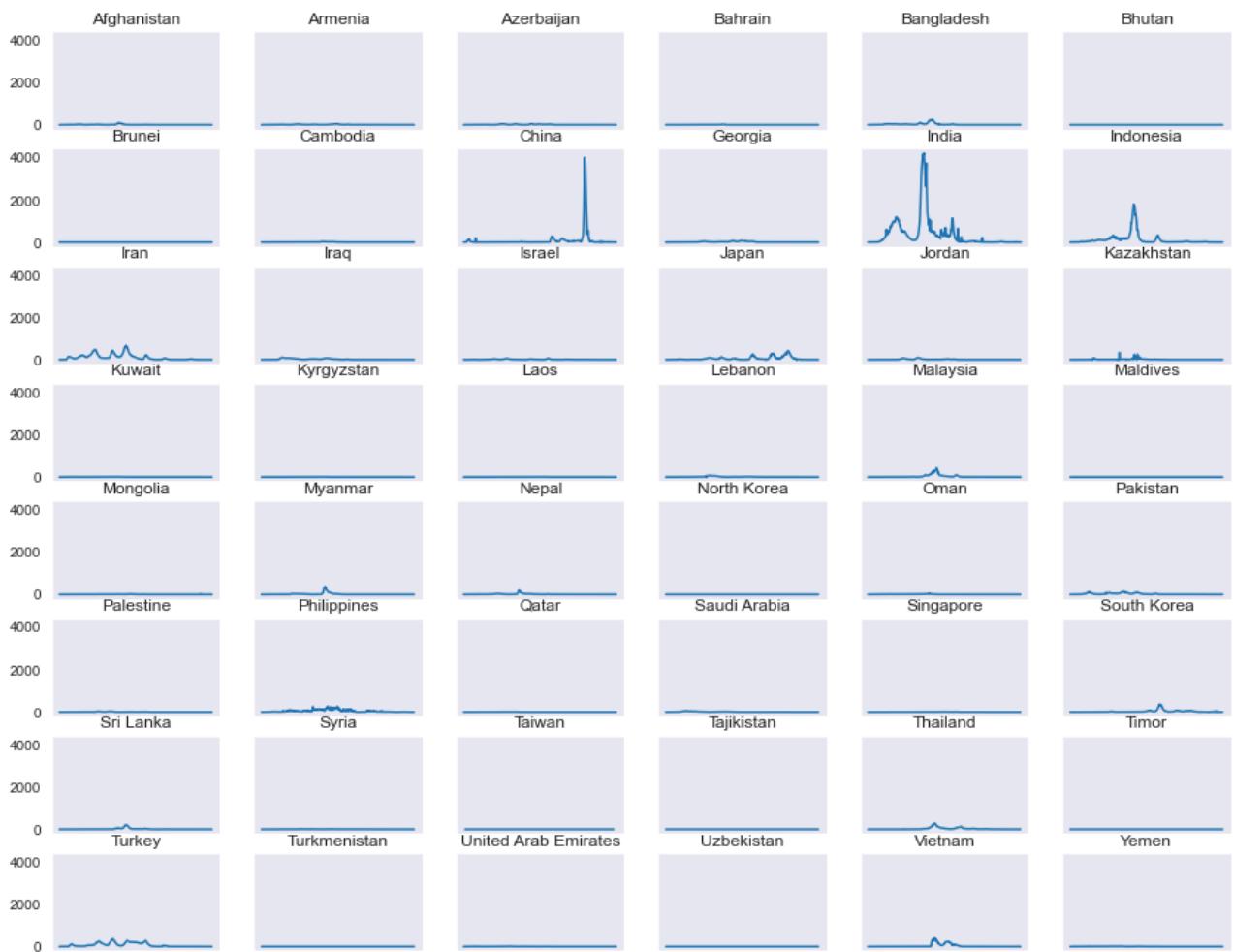
for i,country in enumerate(df_asia['location'].unique()):
    row = i // 6
    col = i % 6
    ax = axes[row, col]

    mask = df_asia['location'] == country
    x = df_asia.loc[mask, 'date'].unique()
    y = df_asia.loc[mask, 'new_deaths_smoothed']

    ax.plot(x, y)
    ax.set_title(country)
    ax.set_xticks([])

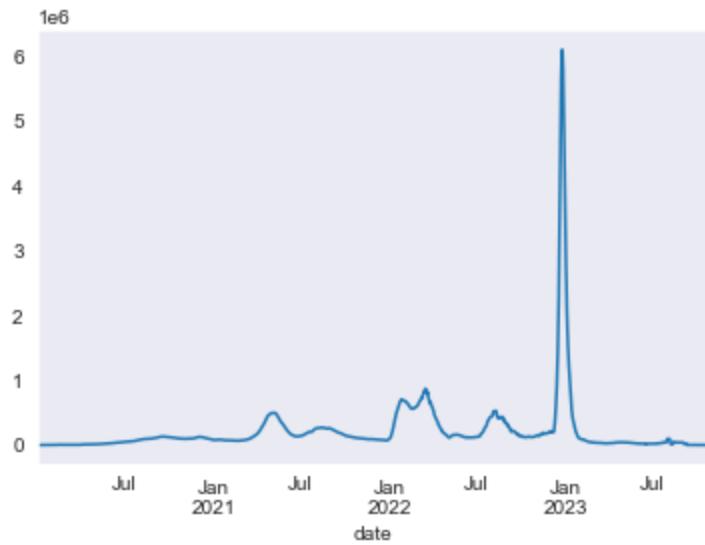
plt.suptitle('New Deaths by Country by Date', fontsize='x-large');
```

New Deaths by Country by Date



- The spike in China in January 2023 is due to the end of 'zero COVID' standard.
- The spike in India in June of 2021 is due in part to the Delta Variant that was rampant at the time.
- Even with these known explanations for the spikes we are seeing, they are still notable outliers.

```
In [47]: # Look at new_cases_smoothed aggregated  
df_asia_ts['new_cases_smoothed'].plot();
```



In [48]: # Look at new_cases_smoothed by country

```
fig, axes = plt.subplots(ncols=6, nrows=8, figsize=(15,15), sharey=True, sharex=True)

for i,country in enumerate(df_asia['location'].unique()):
    row = i // 6
    col = i % 6
    ax = axes[row, col]

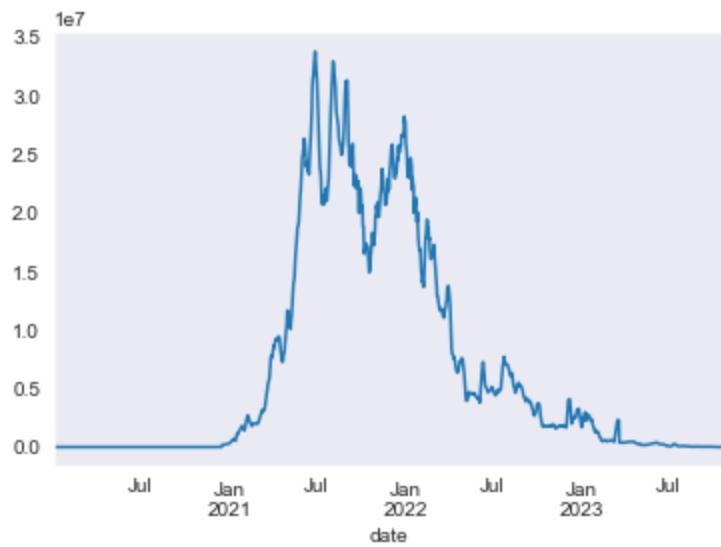
    mask = df_asia['location'] == country
    x = df_asia.loc[mask, 'date'].unique()
    y = df_asia.loc[mask, 'new_cases_smoothed']

    ax.plot(x, y)
    ax.set_title(country)
    ax.set_xticks([]);
```



Again, we can attribute this spike seen in 2023 in China to the end of 'Zero-Covid' policies.

```
In [49]: # Look at new_vaccinations_smoothed aggregated  
df_asia_ts['new_vaccinations_smoothed'].plot();
```



In [50]:

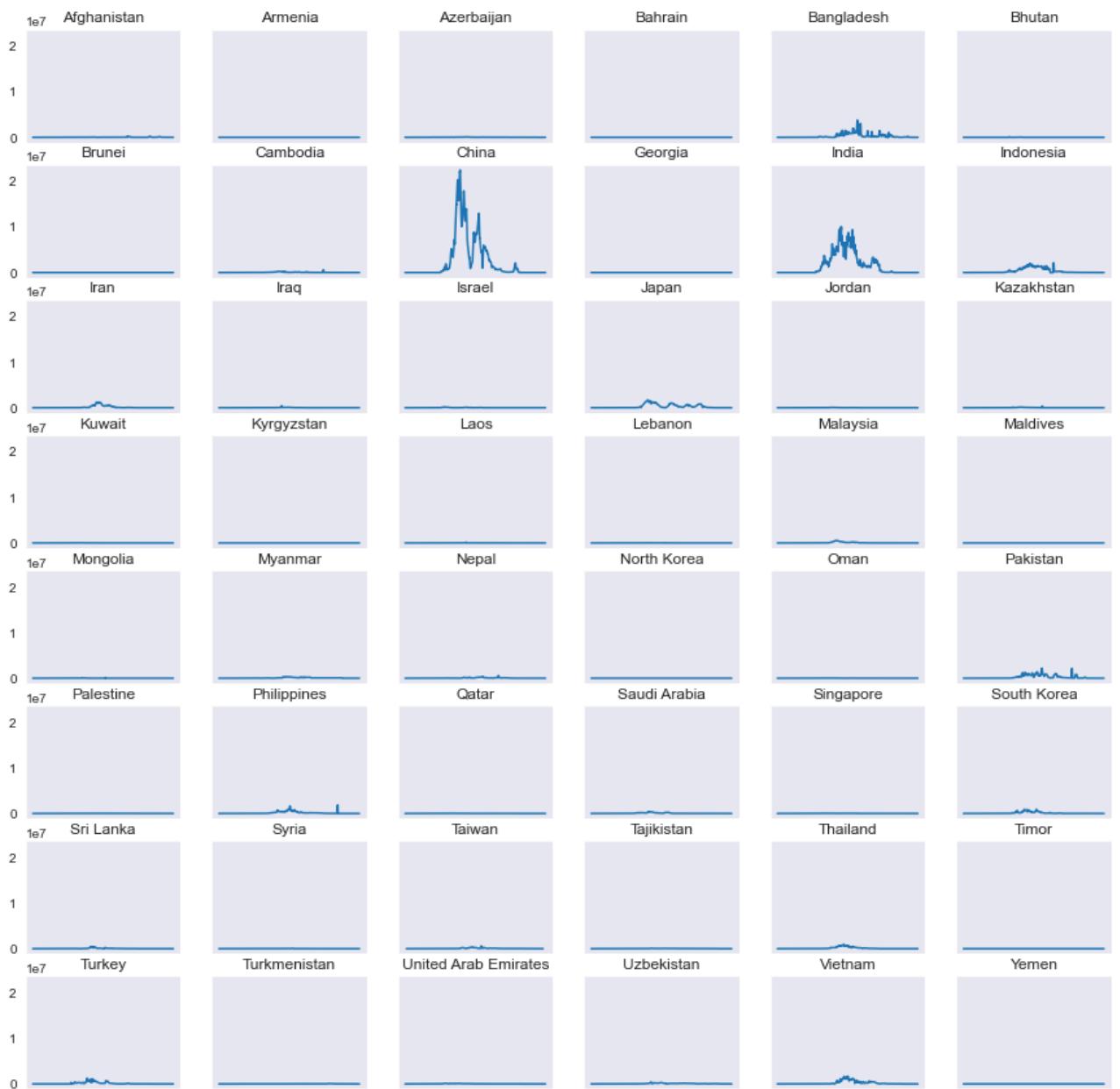
Look at new_vaccinations smoothed by country

```
fig, axes = plt.subplots(ncols=6, nrows=8, figsize=(15,15), sharey=True, sharex=True)

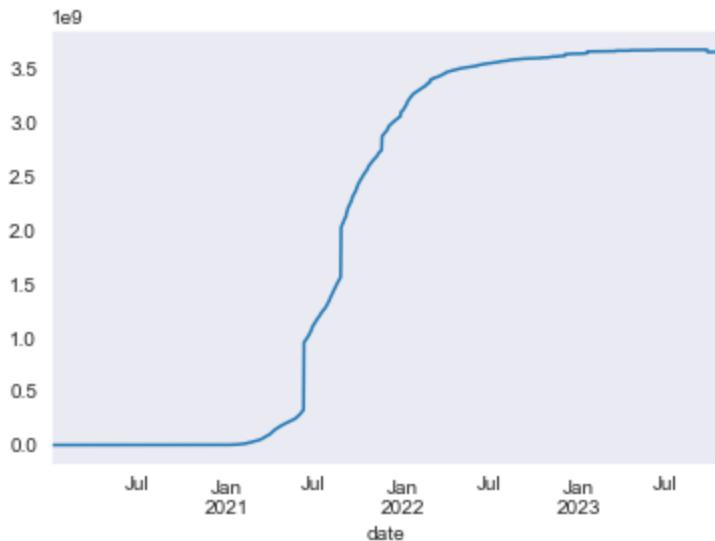
for i,country in enumerate(df_asia['location'].unique()):
    row = i // 6
    col = i % 6
    ax = axes[row, col]

    mask = df_asia['location'] == country
    x = df_asia.loc[mask, 'date'].unique()
    y = df_asia.loc[mask, 'new_vaccinations_smoothed']

    ax.plot(x, y)
    ax.set_title(country)
    ax.set_xticks([]);
```



```
In [51]: # Look at people_vaccinated aggregated  
df_asia_ts['people_vaccinated'].plot();
```



That is an unusual trend at the end there that we would not expect to see as this is a cumulative value -- it should never be smaller than its previous value. Let's investigate this further and fix.

```
In [52]: # Look at the last 8 days in the dataset  
df_asia_ts['people_vaccinated'][-8:]
```

```
Out[52]: date  
2023-10-16    3.656579e+09  
2023-10-17    3.656579e+09  
2023-10-18    3.656579e+09  
2023-10-19    1.207039e+09  
2023-10-20    1.055535e+09  
2023-10-21    1.055535e+09  
2023-10-22    1.027419e+09  
2023-10-23    1.027419e+09  
Name: people_vaccinated, dtype: float64
```

```
In [53]: # Some countries must not have data for the last 5 days which is causing the average  
# Will move forward with using the value found on the 18th as the last value for the  
  
list_ = []  
list_.append(df_asia_ts['people_vaccinated'][-8])  
list_ = list_* 5  
df_asia_ts['people_vaccinated'][-5:] = list_  
  
df_asia_ts['people_vaccinated'][-8:]
```

```
Out[53]: date  
2023-10-16    3.656579e+09  
2023-10-17    3.656579e+09  
2023-10-18    3.656579e+09  
2023-10-19    3.656579e+09  
2023-10-20    3.656579e+09  
2023-10-21    3.656579e+09  
2023-10-22    3.656579e+09  
2023-10-23    3.656579e+09  
Name: people_vaccinated, dtype: float64
```

In [54]:

```
# Look at people_vaccinated by country
fig, axes = plt.subplots(ncols=6, nrows=8, figsize=(15,15), sharey=True, sharex=True)

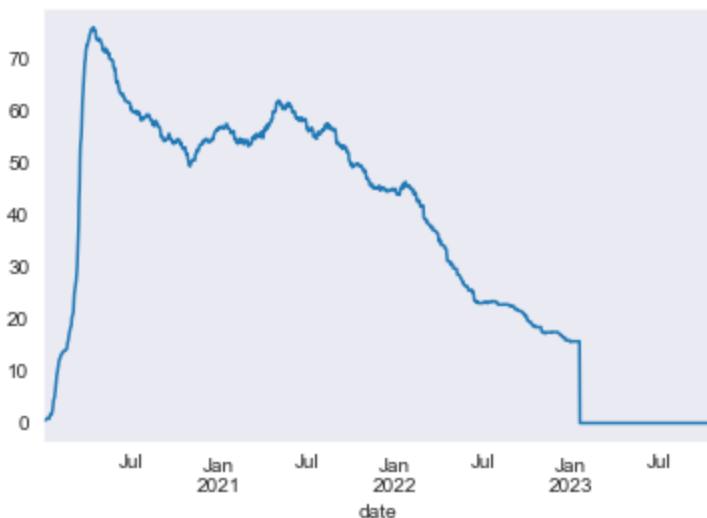
for i,country in enumerate(df_asia['location'].unique()):
    row = i // 6
    col = i % 6
    ax = axes[row, col]

    mask = df_asia['location'] == country
    x = df_asia.loc[mask, 'date'].unique()
    y = df_asia.loc[mask, 'people_vaccinated']

    ax.plot(x, y)
    ax.set_title(country)
    ax.set_xticks([]);
```



In [55]: # Look at stringency_index aggregated
df_asia_ts['stringency_index'].plot();



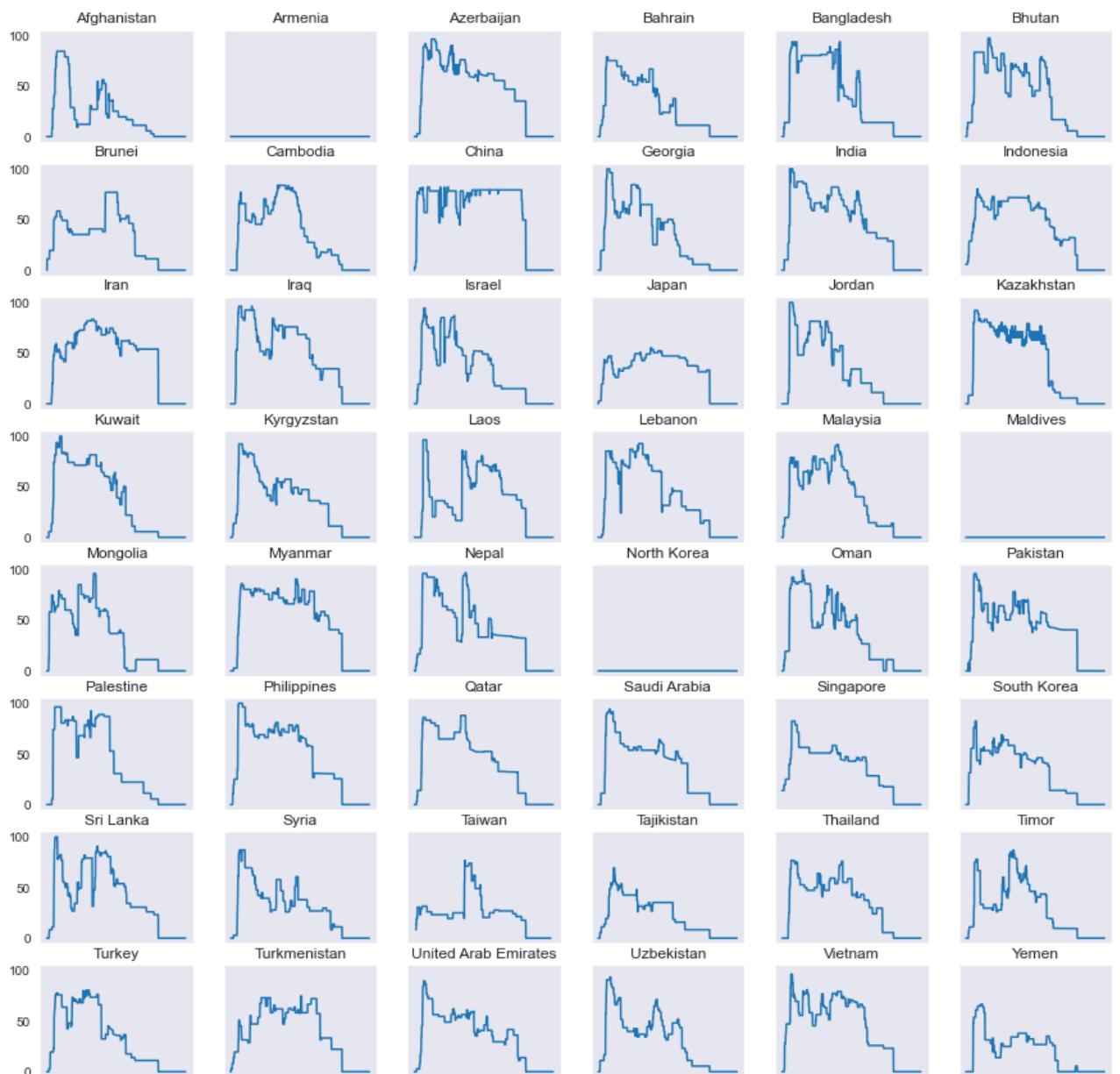
In [56]:

```
# Look at stringency_index by country
fig, axes = plt.subplots(ncols=6, nrows=8, figsize=(15,15), sharey=True, sharex=True)

for i,country in enumerate(df_asia['location'].unique()):
    row = i // 6
    col = i % 6
    ax = axes[row, col]

    mask = df_asia['location'] == country
    x = df_asia.loc[mask, 'date'].unique()
    y = df_asia.loc[mask, 'stringency_index']

    ax.plot(x, y)
    ax.set_title(country)
    ax.set_xticks([]);
```



Modeling

The project goes through various different models:

1. Naive Model (Baseline)
2. ARIMA (using auto_arima to find best parameters)
3. Multivariate ARIMA
4. Linear Regression
5. Prophet
6. Multivariate Prophet

All of the above models, aside from Linear Regression, are traditionally used for time series modeling. The Linear Regression, while not traditionally used for forecasting future date predictions, will be a good comparison.

Each model makes a prediction for the validation set dates, and then is evaluated with the mean absolute error and root mean squared error. Both of these metrics are commonly used when evaluating time series models. We will be looking at both metrics as RMSE gives greater punishment to larger errors, which is generally good, however it does make it more sensitive to outliers. Looking at our data, we clearly have identified some unusual spikes. Thus we will also take a look at the MAE as this more robust to outliers.

Each model is compared using this error prior to choosing the final model to evaluate with the test set. We also look at the AIC for the model when applicable.

Train/Validate/Test Split

```
In [57]: ┌─ print('Train set will consist of approximately the first {} dates'.format(len(df_asia)))
   ┌─ print('Validate set will consist of approximately the next {} dates'.format(len(df_a
   ┌─ print('Test set will consist of approximately the last {} dates'.format(len(df_asia_
```

Train set will consist of approximately the first 1112.0 dates
 Validate set will consist of approximately the next 139.0 dates
 Test set will consist of approximately the last 139.0 dates

```
In [58]: ┌─ # Train Set
   ┌─ first_80_perc = len(df_asia_ts.index) * .8
   ┌─ mask = df_asia_ts.index[:int(first_80_perc)]
   ┌─ train = df_asia_ts.loc[mask]
   ┌─ train.info()
```

#	Column	Non-Null Count	Dtype
0	stringency_index	1112 non-null	float64
1	new_cases_smoothed	1112 non-null	float64
2	new_deaths_smoothed	1112 non-null	float64
3	people_vaccinated	1112 non-null	float64
4	new_vaccinations_smoothed	1112 non-null	float64

<class 'pandas.core.frame.DataFrame'>
 DatetimeIndex: 1112 entries, 2020-01-03 to 2023-01-18
 Data columns (total 5 columns):
Column Non-Null Count Dtype
--- --
0 stringency_index 1112 non-null float64
1 new_cases_smoothed 1112 non-null float64
2 new_deaths_smoothed 1112 non-null float64
3 people_vaccinated 1112 non-null float64
4 new_vaccinations_smoothed 1112 non-null float64
dtypes: float64(5)
memory usage: 52.1 KB

In [59]:

```
# Validate Set
val_perc = 139 + int(first_80_perc)
mask = df_asia_ts.index[int(first_80_perc):val_perc]
validate = df_asia_ts.loc[mask]
validate.info()
```

```
<class 'pandas.core.frame.DataFrame'>
DatetimeIndex: 139 entries, 2023-01-19 to 2023-06-06
Data columns (total 5 columns):
 #   Column           Non-Null Count  Dtype  
--- 
 0   stringency_index    139 non-null    float64
 1   new_cases_smoothed  139 non-null    float64
 2   new_deaths_smoothed 139 non-null    float64
 3   people_vaccinated   139 non-null    float64
 4   new_vaccinations_smoothed 139 non-null    float64
dtypes: float64(5)
memory usage: 6.5 KB
```

In [60]:

```
# Test Set
mask = df_asia_ts.index[val_perc:]
test = df_asia_ts.loc[mask]
test.info()
```

```
<class 'pandas.core.frame.DataFrame'>
DatetimeIndex: 139 entries, 2023-06-07 to 2023-10-23
Data columns (total 5 columns):
 #   Column           Non-Null Count  Dtype  
--- 
 0   stringency_index    139 non-null    float64
 1   new_cases_smoothed  139 non-null    float64
 2   new_deaths_smoothed 139 non-null    float64
 3   people_vaccinated   139 non-null    float64
 4   new_vaccinations_smoothed 139 non-null    float64
dtypes: float64(5)
memory usage: 6.5 KB
```

Baseline -- Naive Model

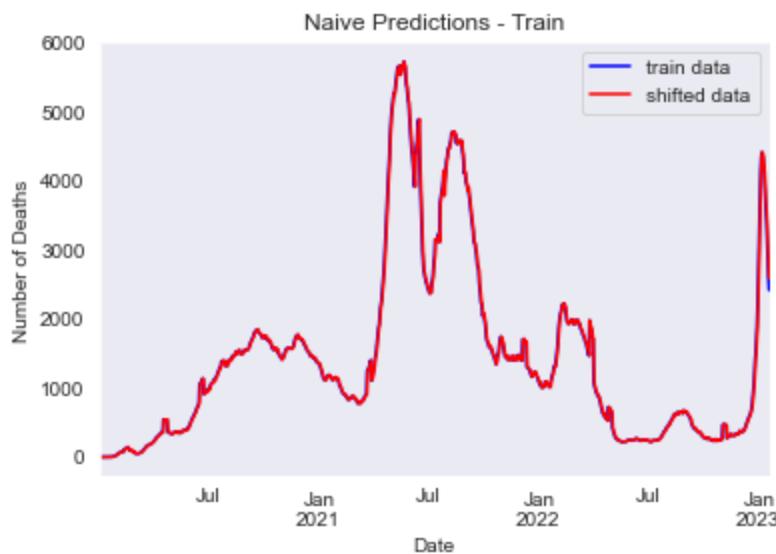
The Naive Method is to predict that the value tomorrow will be the same value that is seen today. Thus we will shift our data by one for our 'predictions'. We also look a bit further into our data, looking at the rolling standard deviation and variance of the residuals prior to forecasting for the validation dates and evaluating the RMSE.

In [61]:

```
# The Naive "Model"
baseline = train['new_deaths_smoothed'].shift(1)

# Visualize f
fig, ax = plt.subplots()

train['new_deaths_smoothed'].plot(ax=ax, c='b', label='train data')
baseline.plot(ax=ax, c='r', label='shifted data')
ax.set_title('Naive Predictions - Train')
ax.set_ylabel('Number of Deaths')
ax.set_xlabel('Date')
ax.legend();
```



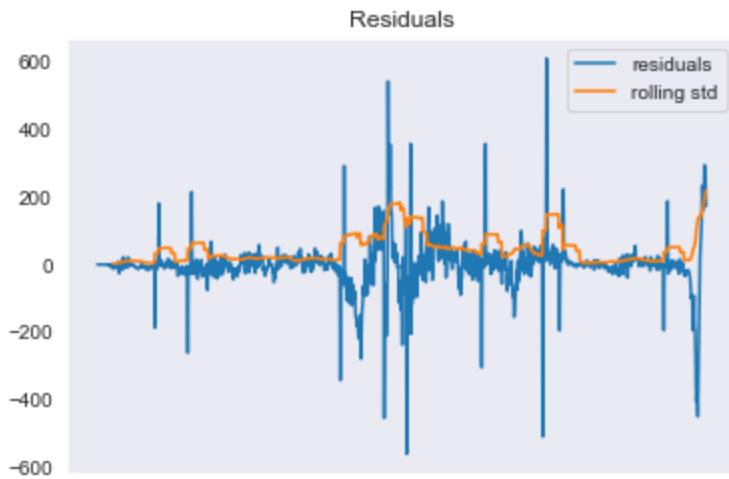
In [62]:

```
# Train RMSE
baseline_error_train = np.sqrt(mean_squared_error(train['new_deaths_smoothed'][1:], baseline.dropna()))
baseline_error_train
```

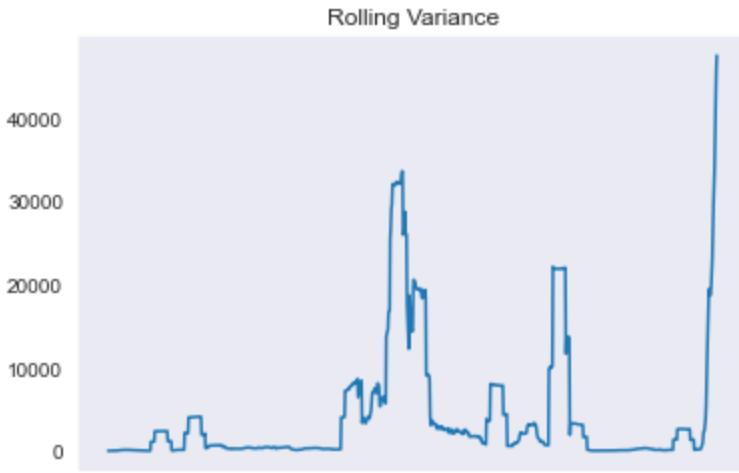
Out[62]: 74.98148522286566

```
In [63]: # Look for trends -- want residuals to look like white noise  
fig, ax = plt.subplots()
```

```
residuals = baseline[1:] - train['new_deaths_smoothed'][1:]  
ax.plot(residuals.index, residuals, label='residuals')  
ax.plot(residuals.index, residuals.rolling(30).std(), label='rolling std')  
ax.set_xticks([])  
ax.set_title('Residuals')  
ax.legend();
```



```
In [64]: # check variance  
fig, ax = plt.subplots()  
ax.plot(residuals.index, residuals.rolling(30).var())  
ax.set_xticks([])  
ax.set_title('Rolling Variance');
```



```
In [65]: # "Predict" -- use last known data point for all future predictions
y_preds_baseline = []
y_preds_baseline.append(validate[-1])
y_preds_baseline = y_preds_baseline * len(validate.index)

# For evaluation, assign y_train and y_val
y_train = train['new_deaths_smoothed']
y_val = validate['new_deaths_smoothed']
```

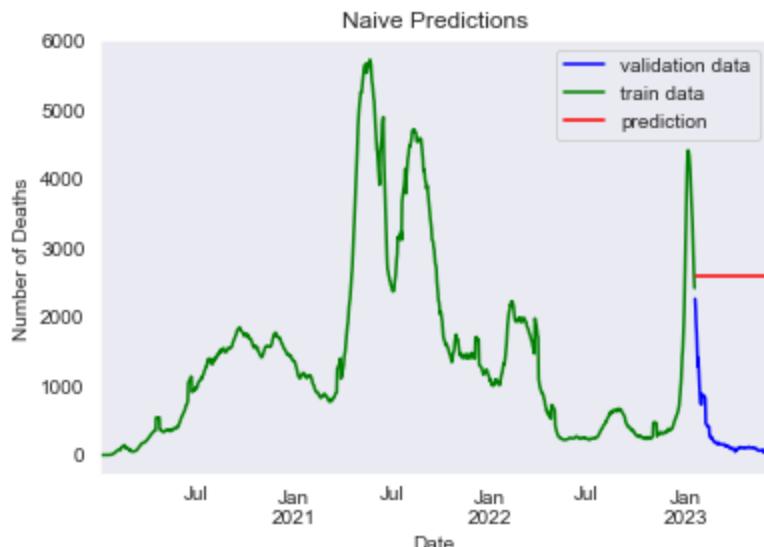
```
In [66]: def graph_preds(train_data, validate_data, y_pred, model_name):
    """
    This function takes in the values the model was trained on, and the true validation
    both as pandas series with the date as the index. It also takes in the predicted
    or pandas series, and graphs all three on a single axis.

    Expected input:
        train_data | pandas series, with datetime as index, of the target training data
        validate_data | pandas series, with datetime as index, of the target validation data
        y_pred | list of the target predictions
        model_name | string

    Expected output: matplotlib graph of the target training data, validation data,
                    plotted against the date
    """
    fig, ax = plt.subplots()

    validate_data.plot(ax=ax, color='b', label='validation data')
    train_data.plot(ax=ax, color='g', label='train data')
    ax.plot(validate_data.index, y_pred, color='r', label='prediction')
    ax.set_title(model_name + ' Predictions')
    ax.set_ylabel('Number of Deaths')
    ax.set_xlabel('Date')
    ax.legend();
```

```
In [67]: # Visualize
graph_preds(y_train, y_val, y_preds_baseline, 'Naive')
```



In [68]: # Record Evaluation Results

```
all_results = {'model': [], 'rmse':[], 'mae':[],'train_aic':[]}

def evaluate(y_true, y_pred, all_results, model_name, aic):
    """
    This function takes in a y_true, y_pred, a dictionary called all_results, and a
    It calculates the RMSE, prints it, and appends it and the model_name to the appr

    Expected input:
        y_true | true target values as a pandas series or list
        y_pred | target predictions as a pandas series or list
        all_results | python dictionary
        model_name | string
        aic | number or np.nan

    Expected output: print out of the updated dictionary, all_results
    """
    # RMSE
    rmse = mean_squared_error(y_true, y_pred, squared=False)

    # MAE
    mae = mean_absolute_error(y_true, y_pred)

    # Add to dictionary
    all_results['model'].append(model_name)
    all_results['rmse'].append(rmse)
    all_results['mae'].append(mae)
    all_results['train_aic'].append(aic)

    print(all_results)
```

In [69]: # evaluate

```
evaluate(y_val, y_preds_baseline, all_results, 'Naive', np.nan)
```

```
{'model': ['Naive'], 'rmse': [2342.568668178121], 'mae': [2305.21582733813], 'train_aic': [nan]}
```

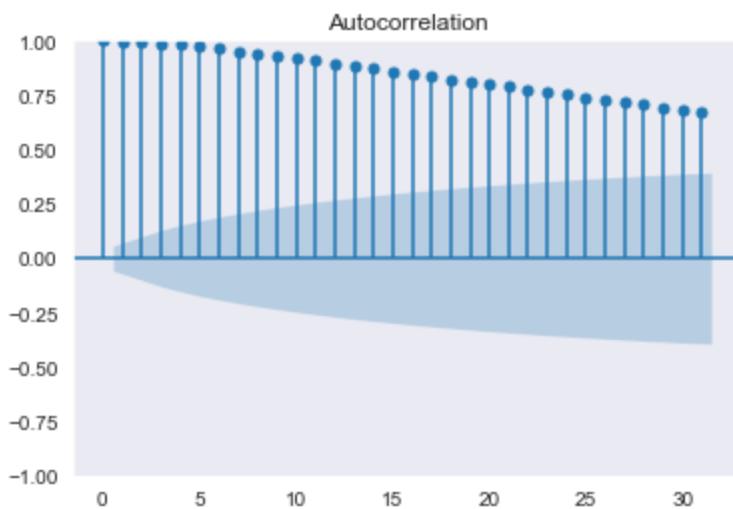
Model 2 - ARIMA

Before jumping into the auto_arima function which performs a grid-search-like function internally to achieve the optimal p, d, and q values, we take a look at the ACF and PACF graphs (for both the original data as well as the once differenced data) to better understand the time series data. We also visualize the differenced data and perform a Dickey-Fuller test to ascertain whether or not the differenced data is stationary.

After that manual work, we move forward into utilizing the auto_arima function which does that work for us. The model is created and then evaluated.

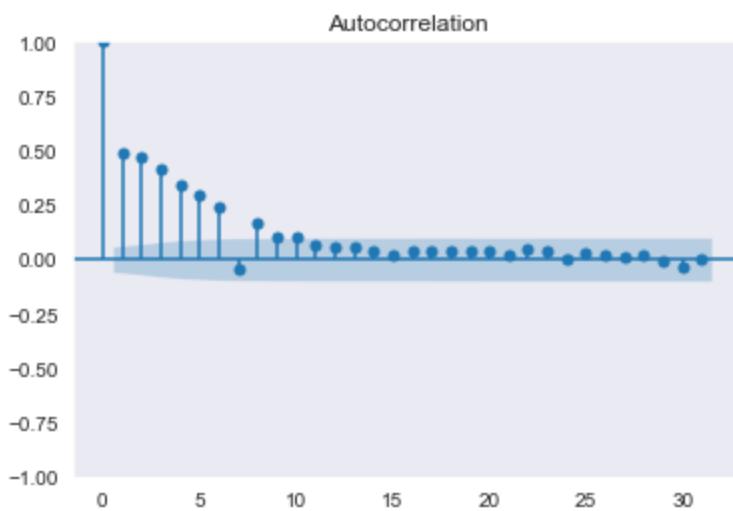
In [70]:

```
# ACF  
fig, ax = plt.subplots()  
plot_acf(train['new_deaths_smoothed'], ax=ax);
```

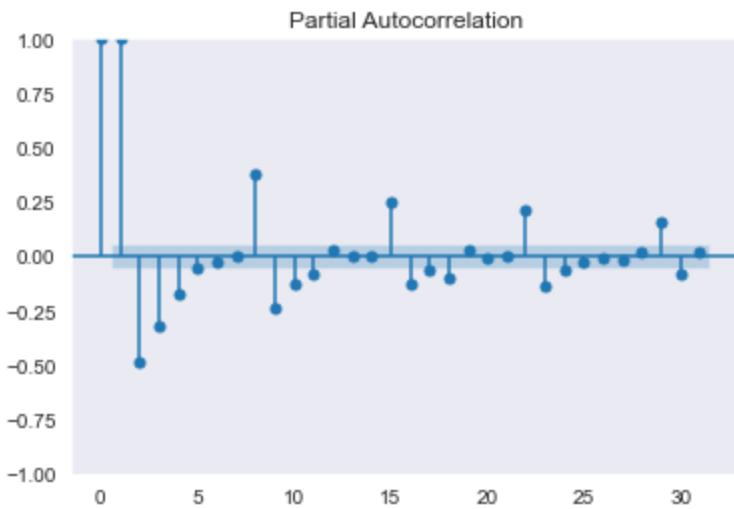


In [71]:

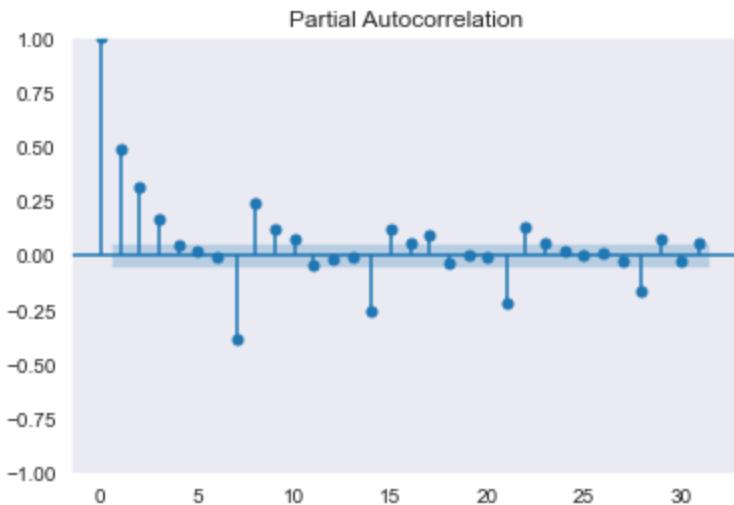
```
# Take the first difference -- now plot ACF  
fig, ax = plt.subplots()  
data = train['new_deaths_smoothed'].diff().dropna()  
plot_acf(data, ax=ax);
```



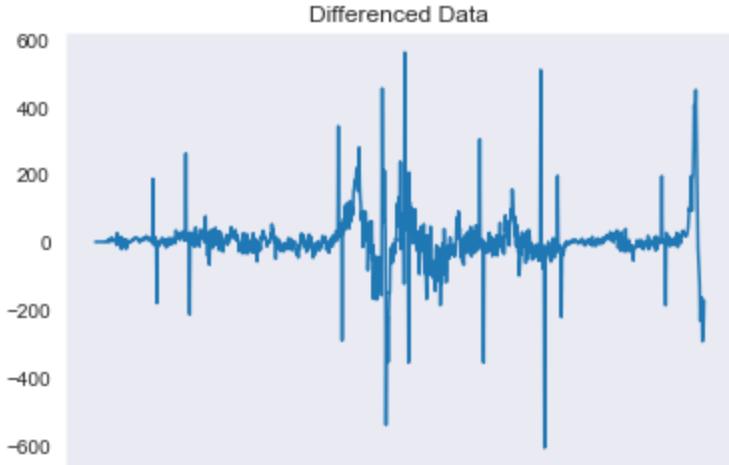
```
In [72]: # PACF (correlation between current time period + lags  
# accounting for the correlation between the intermediate time periods)  
fig, ax = plt.subplots()  
plot_pacf(train['new_deaths_smoothed'], ax=ax, method='ols-adjusted');
```



```
In [73]: # PACF of differenced data  
fig, ax = plt.subplots()  
data = train['new_deaths_smoothed'].diff().dropna()  
plot_pacf(data, ax=ax, method='ols-adjusted');
```



```
In [74]: # Visualize Differenced Data
fig, ax = plt.subplots()
ax.plot(train['new_deaths_smoothed'].diff().dropna())
ax.set_title('Differenced Data')
ax.set_xticks([]);
```



```
In [75]: # Check if the once differenced data is stationary
```

```
p_val = adfuller(train['new_deaths_smoothed'].diff()[1:])[1]
print(f"The p-value associated with the Dickey-Fuller statistical test is {p_val},")
```



```
if p_val < 0.05:
    print("Thus we can safely assume that the differenced data is stationary.")
else:
    print("Thus we cannot reject the null hypothesis that the differenced data is \
not stationary.")
```

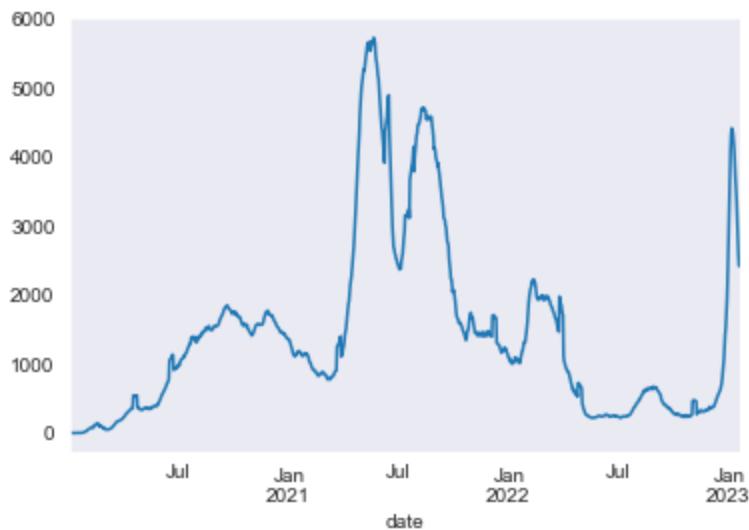
The p-value associated with the Dickey-Fuller statistical test is 1.831271274295940
5e-06,

Thus we can safely assume that the differenced data is stationary.

Based on the adjusted Dickey-Fuller test, we can assert that the once differenced data is stationary which means it is suitable for modeling. However, based on the ACF and PACF visuals, even of the differenced data, we know we will need to include some autoregressive (AR) and moving average (MA) terms.

Let's also take a look at the data once again to see if we should include any seasonality terms in our model.

```
In [76]: ┌ # Look for seasonality trends  
y_train.plot();
```



There does not appear to be any seasonality trends present in our data (on the weekly, monthly, nor yearly scale). We will move forward with excluding these features from our model.

```
In [77]: ┌ # auto_arima function parameters -- values chosen + notes  
  
# time series to train on + predict  
y_train = train['new_deaths_smoothed']  
# no constants  
X_train = train[['new_cases_smoothed', 'people_vaccinated', 'new_vaccinations_smoothed']]  
  
# AR term  
start_p = 1  
max_p = 5 # default  
  
# Order of non-seasonal first-differencing  
d=None # default -- calculated  
max_d = 2 # default -- from above we know 1 difference is stationary  
  
# MA term  
start_q = 1  
max_q = 5 # default  
  
# Seasonality  
seasonal = False  
  
# Evaluation to select best ARIMA model  
information_criterion = 'aic' # default  
  
# Level of significance  
alpha = 0.05 # default  
  
# Scoring default is MSE
```

In [78]:

```
# ARIMA Model
arima = auto_arima(y_train, start_p=start_p, start_q=start_q, seasonal=False, trace=1)

Performing stepwise search to minimize aic
ARIMA(1,1,1)(0,0,0)[0] intercept      : AIC=12319.179, Time=0.37 sec
ARIMA(0,1,0)(0,0,0)[0] intercept      : AIC=12748.856, Time=0.02 sec
ARIMA(1,1,0)(0,0,0)[0] intercept      : AIC=12450.579, Time=0.08 sec
ARIMA(0,1,1)(0,0,0)[0] intercept      : AIC=12571.953, Time=0.13 sec
ARIMA(0,1,0)(0,0,0)[0]                : AIC=12747.791, Time=0.02 sec
ARIMA(2,1,1)(0,0,0)[0] intercept      : AIC=12309.801, Time=0.25 sec
ARIMA(2,1,0)(0,0,0)[0] intercept      : AIC=12337.492, Time=0.06 sec
ARIMA(3,1,1)(0,0,0)[0] intercept      : AIC=12308.240, Time=0.36 sec
ARIMA(3,1,0)(0,0,0)[0] intercept      : AIC=12308.637, Time=0.09 sec
ARIMA(4,1,1)(0,0,0)[0] intercept      : AIC=12309.883, Time=0.30 sec
ARIMA(3,1,2)(0,0,0)[0] intercept      : AIC=inf, Time=0.87 sec
ARIMA(2,1,2)(0,0,0)[0] intercept      : AIC=12275.377, Time=0.60 sec
ARIMA(1,1,2)(0,0,0)[0] intercept      : AIC=12306.198, Time=0.27 sec
ARIMA(2,1,3)(0,0,0)[0] intercept      : AIC=inf, Time=0.91 sec
ARIMA(1,1,3)(0,0,0)[0] intercept      : AIC=12286.262, Time=0.35 sec
ARIMA(3,1,3)(0,0,0)[0] intercept      : AIC=inf, Time=1.19 sec
ARIMA(2,1,2)(0,0,0)[0]                : AIC=12273.588, Time=0.30 sec
ARIMA(1,1,2)(0,0,0)[0]                : AIC=12304.229, Time=0.19 sec
ARIMA(2,1,1)(0,0,0)[0]                : AIC=12307.829, Time=0.14 sec
ARIMA(3,1,2)(0,0,0)[0]                : AIC=inf, Time=0.50 sec
ARIMA(2,1,3)(0,0,0)[0]                : AIC=inf, Time=0.67 sec
ARIMA(1,1,1)(0,0,0)[0]                : AIC=12317.200, Time=0.13 sec
ARIMA(1,1,3)(0,0,0)[0]                : AIC=12284.319, Time=0.24 sec
ARIMA(3,1,1)(0,0,0)[0]                : AIC=12306.270, Time=0.23 sec
ARIMA(3,1,3)(0,0,0)[0]                : AIC=inf, Time=0.85 sec

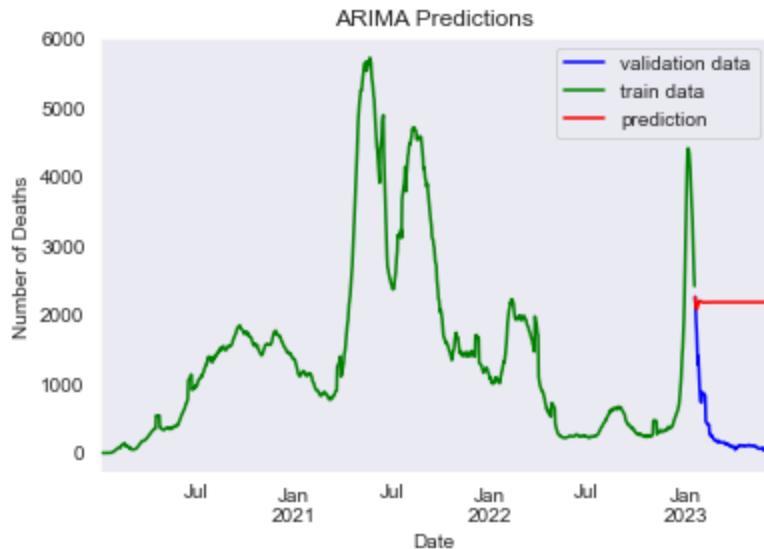
Best model: ARIMA(2,1,2)(0,0,0)[0]
Total fit time: 9.166 seconds
```

In [79]:

```
# Future dates to forecast
n_periods_pred = validate['new_deaths_smoothed'].shape[0]
```

```
In [80]: # Predict
y_preds_arima = arima.predict(n_periods=n_periods_pred)

# Visualize
graph_preds(y_train, y_val, y_preds_arima, 'ARIMA')
```



```
In [81]: # AIC
arima_aic = arima.aic()
```

```
In [82]: # evaluate
evaluate(y_val, y_preds_arima, all_results, 'ARIMA', arima_aic)
```

```
{'model': ['Naive', 'ARIMA'], 'rmse': [2342.568668178121, 1943.663337601336], 'mae': [2305.21582733813, 1897.0728151796197], 'train_aic': [nan, 12273.587689666143]}
```

We can see that our RMSE and MAE have both improved from our baseline predictions. Let's see if we can improve that even further.

Model 3 - Multivariate ARIMA

Rather than just use the target variable, the true 'time series' data of `new_deaths_smoothed`, we will incorporate the other variables that we have available to us.

In [83]:

```
# Multivariate ARIMA model
arima_multi = auto_arima(y_train, X_train, start_p=start_p, start_q=start_q, seasonal=False)

Performing stepwise search to minimize aic
ARIMA(1,1,1)(0,0,0)[0] intercept      : AIC=12292.082, Time=0.37 sec
ARIMA(0,1,0)(0,0,0)[0] intercept      : AIC=12725.721, Time=0.57 sec
ARIMA(1,1,0)(0,0,0)[0] intercept      : AIC=12419.089, Time=0.28 sec
ARIMA(0,1,1)(0,0,0)[0] intercept      : AIC=12555.246, Time=0.33 sec
ARIMA(0,1,0)(0,0,0)[0]                : AIC=19405.347, Time=0.21 sec
ARIMA(2,1,1)(0,0,0)[0] intercept      : AIC=12274.985, Time=0.38 sec
ARIMA(2,1,0)(0,0,0)[0] intercept      : AIC=12300.733, Time=0.36 sec
ARIMA(3,1,1)(0,0,0)[0] intercept      : AIC=12273.326, Time=0.44 sec
ARIMA(3,1,0)(0,0,0)[0] intercept      : AIC=12270.068, Time=0.44 sec
ARIMA(4,1,0)(0,0,0)[0] intercept      : AIC=12269.356, Time=0.56 sec
ARIMA(5,1,0)(0,0,0)[0] intercept      : AIC=12270.779, Time=0.58 sec
ARIMA(4,1,1)(0,0,0)[0] intercept      : AIC=12271.600, Time=0.55 sec
ARIMA(5,1,1)(0,0,0)[0] intercept      : AIC=12273.016, Time=0.61 sec
ARIMA(4,1,0)(0,0,0)[0]                : AIC=12267.357, Time=0.47 sec
ARIMA(3,1,0)(0,0,0)[0]                : AIC=12268.068, Time=0.39 sec
ARIMA(5,1,0)(0,0,0)[0]                : AIC=12268.781, Time=0.47 sec
ARIMA(4,1,1)(0,0,0)[0]                : AIC=12269.600, Time=0.50 sec
ARIMA(3,1,1)(0,0,0)[0]                : AIC=12271.326, Time=0.41 sec
ARIMA(5,1,1)(0,0,0)[0]                : AIC=12271.017, Time=0.55 sec

Best model: ARIMA(4,1,0)(0,0,0)[0]
Total fit time: 8.480 seconds
```

In [84]: arima_multi.summary()

Out[84]: SARIMAX Results

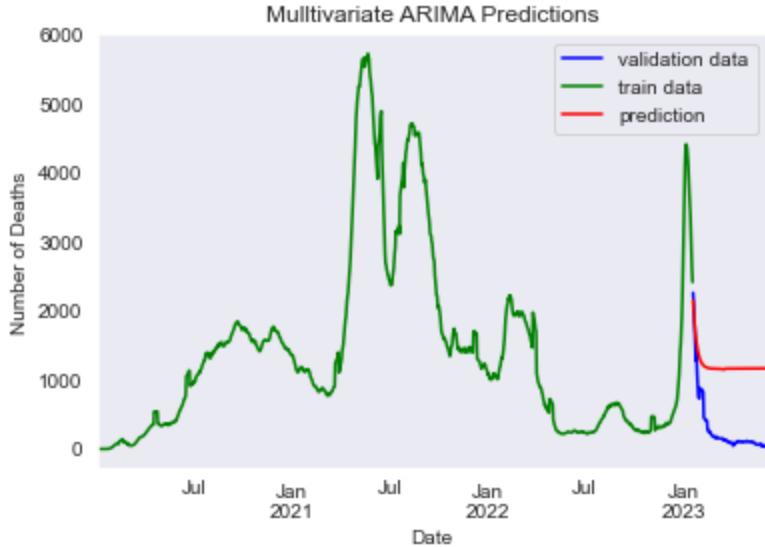
Dep. Variable:	y	No. Observations:	1112			
Model:	SARIMAX(4, 1, 0)	Log Likelihood	-6124.678			
Date:	Thu, 11 Apr 2024	AIC	12267.357			
Time:	07:29:15	BIC	12312.474			
Sample:	01-03-2020 - 01-18-2023	HQIC	12284.416			
Covariance Type:	opg					
	coef	std err	z	P> z	[0.025	0.975]
new_cases_smoothed	-0.0001	3.74e-05	-3.173	0.002	-0.000	-4.54e-05
people_vaccinated	3.749e-07	1.79e-08	20.893	0.000	3.4e-07	4.1e-07
new_vaccinations_smoothed	-4.571e-06	3.97e-06	-1.151	0.250	-1.24e-05	3.21e-06
stringency_index	6.8998	1.83e-05	3.77e+05	0.000	6.900	6.900
ar.L1	0.2741	0.015	17.790	0.000	0.244	0.304
ar.L2	0.2540	0.019	13.602	0.000	0.217	0.291
ar.L3	0.1584	0.022	7.082	0.000	0.115	0.202
ar.L4	0.0500	0.027	1.850	0.064	-0.003	0.103
sigma2	3607.2208	2.9e-06	1.25e+09	0.000	3607.221	3607.221
Ljung-Box (L1) (Q):	0.00	Jarque-Bera (JB):	61962.65			
Prob(Q):	0.97	Prob(JB):	0.00			
Heteroskedasticity (H):	4.71	Skew:	-0.58			
Prob(H) (two-sided):	0.00	Kurtosis:	39.57			

Warnings:

- [1] Covariance matrix calculated using the outer product of gradients (complex-step).
- [2] Covariance matrix is singular or near-singular, with condition number 5.33e+23. Standard errors may be unstable.

```
In [85]: # predict
X_val = validate[['new_cases_smoothed', 'people_vaccinated', 'new_vaccinations_smoothed']]
y_preds_arima_multi = arima_multi.predict(n_periods=n_periods_pred, X=X_val)

#visualize
graph_preds(y_train, y_val, y_preds_arima_multi, 'Multivariate ARIMA')
```



```
In [86]: #AIC
multi_arima_aic = arima_multi.aic()

# evaluate
evaluate(y_val, y_preds_arima_multi, all_results, 'ARIMA Multivariate', multi_arima_aic)

{'model': ['Naive', 'ARIMA', 'ARIMA Multivariate'], 'rmse': [2342.568668178121, 1943.663337601336, 968.1710140037998], 'mae': [2305.21582733813, 1897.0728151796197, 931.2390998209889], 'train_aic': [nan, 12273.587689666143, 12267.356533162601]}
```

Again, we see improvement in both RMSE and MAE.

Model 4 - Linear Regression

While Linear Regressions are typically not suited for time series data, there is no harm in trying it out.

```
In [87]: # Create + fit the model
lr = OLS(y_train, sm.api.add_constant(X_train))
lr_results = lr.fit()
```

In [88]:

```
# Look at summary of model
print(lr_results.summary())
```

OLS Regression Results

Dep. Variable:	new_deaths_smoothed	R-squared:	0.575			
Model:	OLS	Adj. R-squared:	0.573			
Method:	Least Squares	F-statistic:	374.2			
Date:	Thu, 11 Apr 2024	Prob (F-statistic):	7.63e-204			
Time:	07:29:16	Log-Likelihood:	-9094.1			
No. Observations:	1112	AIC:	1.820e+04			
Df Residuals:	1107	BIC:	1.822e+04			
Df Model:	4					
Covariance Type:	nonrobust					
		coef	std err	t	P> t	[0.025
0.975]						

const	568.3413	113.686	4.999	0.000	345.277	
791.406						
new_cases_smoothed	0.0006	4.72e-05	13.747	0.000	0.001	
0.001						
people_vaccinated	-3.033e-07	2.5e-08	-12.123	0.000	-3.52e-07	
-2.54e-07						
new_vaccinations_smoothed	9.572e-05	3.29e-06	29.054	0.000	8.93e-05	
0.000						
stringency_index	9.5100	2.102	4.525	0.000	5.386	
13.634						

Omnibus:	253.509	Durbin-Watson:	0.014			
Prob(Omnibus):	0.000	Jarque-Bera (JB):	726.546			
Skew:	1.148	Prob(JB):	1.71e-158			
Kurtosis:	6.226	Cond. No.	9.99e+09			

Notes:

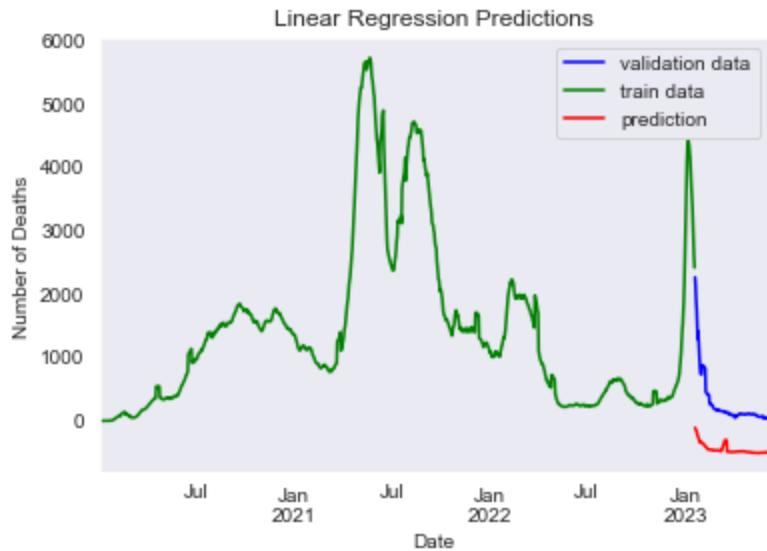
[1] Standard Errors assume that the covariance matrix of the errors is correctly specified.

[2] The condition number is large, 9.99e+09. This might indicate that there are strong multicollinearity or other numerical problems.

In [89]:

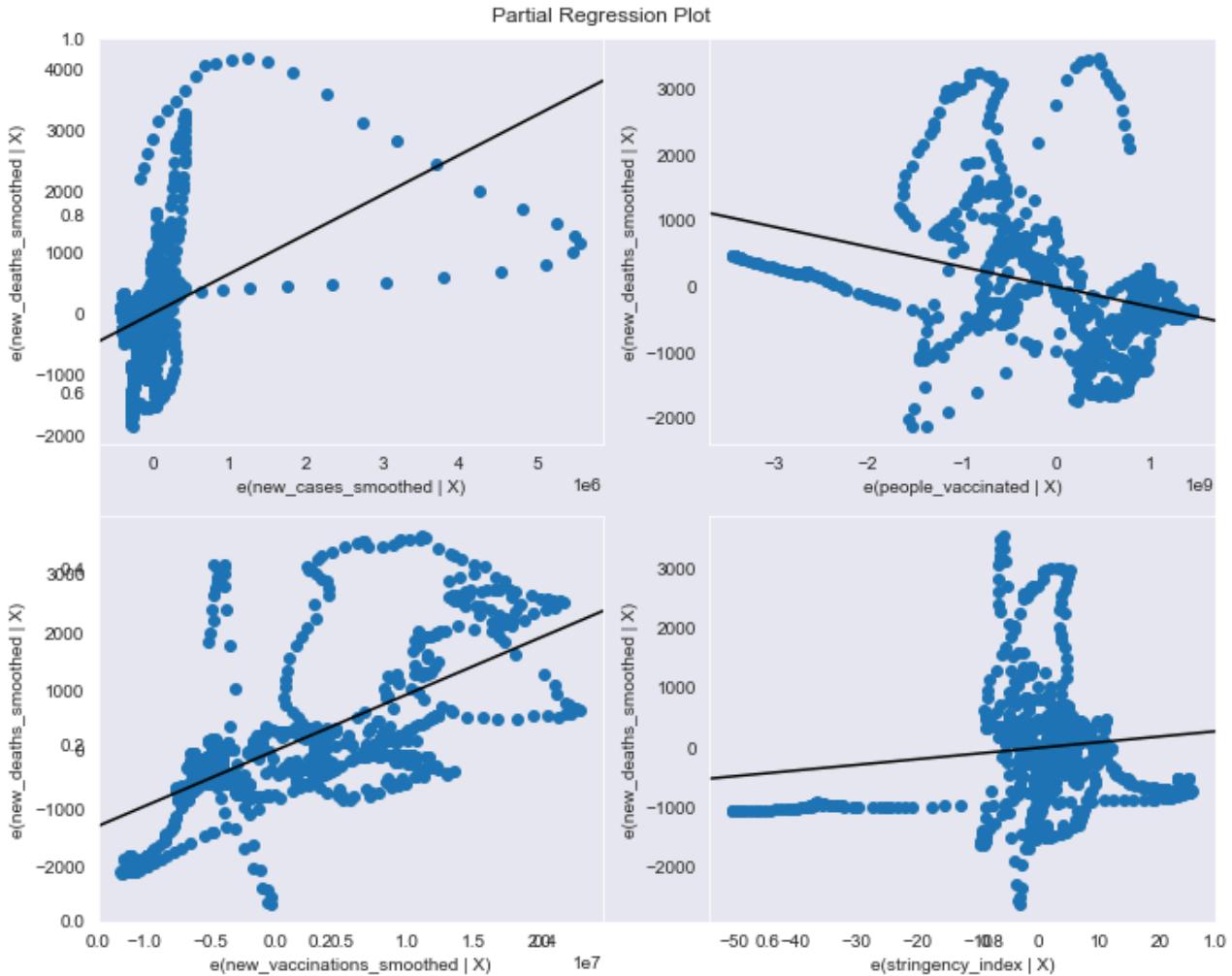
```
# predict
y_preds_lr = lr_results.predict(sm.api.add_constant(X_val))

# Visualize
graph_preds(y_train, y_val, y_preds_lr, 'Linear Regression')
```



In [90]: ► # Look at the partial regression grid for our variables

```
fig, ax = plt.subplots(figsize=(10,8))
sm.graphics.plot_partregress_grid(lr_results,
                                  exog_idx=list(X_train.columns.values),
                                  grid=(2,2),
                                  fig=fig)
plt.show()
```



It is interesting to see here that the relationship between the number of deaths and the number of new vaccinations is positive here. Intuitively, one would predict that as the total number of people vaccinated increases, the number of deaths caused by the disease would decrease.

In [91]: ► # AIC

```
lr_aic = lr_results.aic

# evaluate
evaluate(y_val, y_preds_lr, all_results, 'Linear Regression', lr_aic)
```

```
{'model': ['Naive', 'ARIMA', 'ARIMA Multivariate', 'Linear Regression'], 'rmse': [2342.568668178121, 1943.663337601336, 968.1710140037998, 808.5035575940299], 'mae': [2305.21582733813, 1897.0728151796197, 931.2390998209889, 731.0303773995898], 'train_aic': [nan, 12273.587689666143, 12267.356533162601, 18198.26546916792]}
```

Surprisingly, our Linear Regression model is the most performant model yet! Let's try Facebook's Prophet last to see if we can improve even further.

Model 5 - Facebook's Prophet

The prophet library imposes strict conditions for the input column names, so firstly, some reformatting is done. Then the model is created, visualized (the prophet library has some interesting built in visualizations), and evaluated.

In [92]:

```
# reformat for Prophet
data_train = {'ds': train.index, 'y': y_train.values}
train_prophet = pd.DataFrame.from_dict(data_train)

data_val = {'ds': validate.index, 'y': y_val.values}
val_prophet = pd.DataFrame.from_dict(data_val)
```

In [93]:

```
# create model - default uncertainty is 80% - update to 95%
prophet_model = Prophet(interval_width=0.95)

# Fit Model
prophet_model.fit(train_prophet)
```

```
07:29:18 - cmdstanpy - INFO - Chain [1] start processing
07:29:18 - cmdstanpy - INFO - Chain [1] done processing
```

Out[93]: <prophet.forecaster.Prophet at 0x21c2b9487f0>

In [94]:

```
# predict using future dates
y_preds_prophet = prophet_model.predict(val_prophet[['ds']])
```

In [95]:

```
y_preds_prophet.head()
```

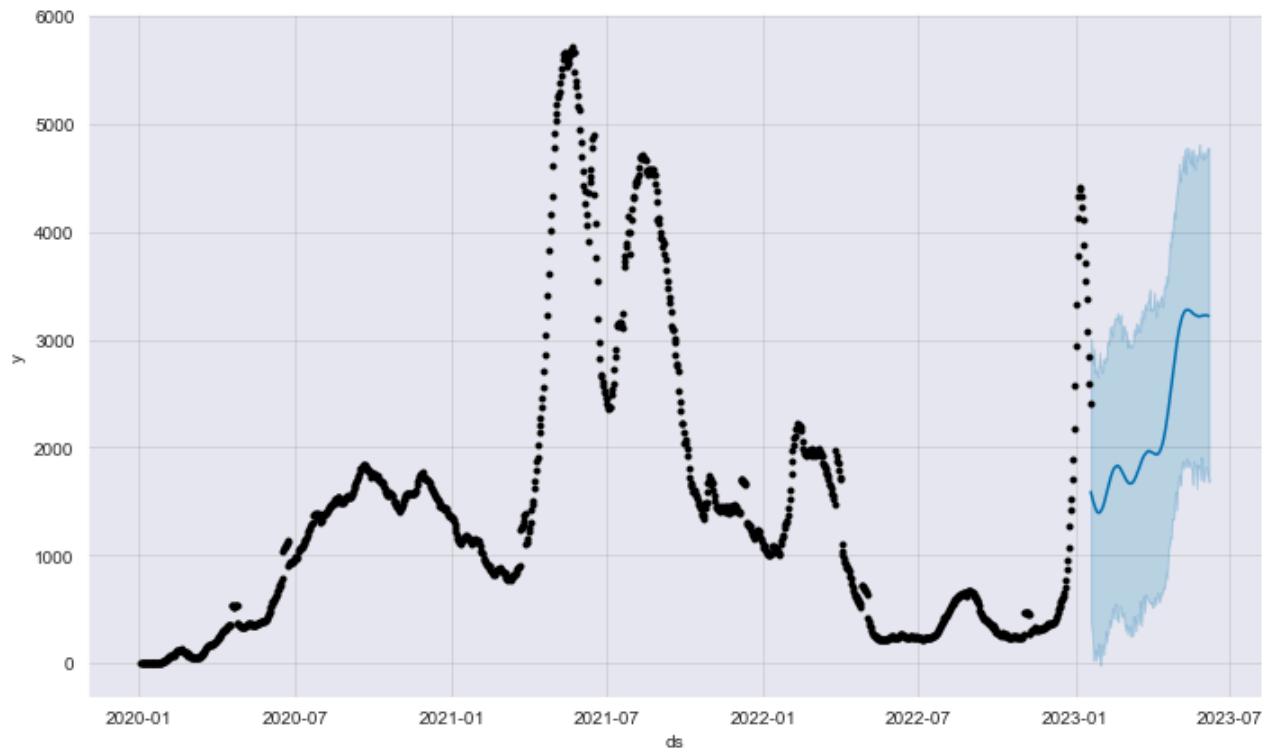
Out[95]:

	ds	trend	yhat_lower	yhat_upper	trend_lower	trend_upper	additive_terms	additive_term
0	2023-01-19	1645.204225	373.437484	3007.548810	1645.204225	1645.204225	-55.307008	-55
1	2023-01-20	1652.476066	302.061509	2939.315279	1652.476066	1652.476066	-95.319351	-95
2	2023-01-21	1659.747908	195.089468	2863.224549	1659.361143	1660.683153	-133.967461	-133
3	2023-01-22	1667.019750	28.869921	2776.737547	1665.977631	1669.794487	-171.116811	-171
4	2023-01-23	1674.291592	80.147240	2917.496121	1672.646526	1678.691962	-205.025594	-205



In [96]:

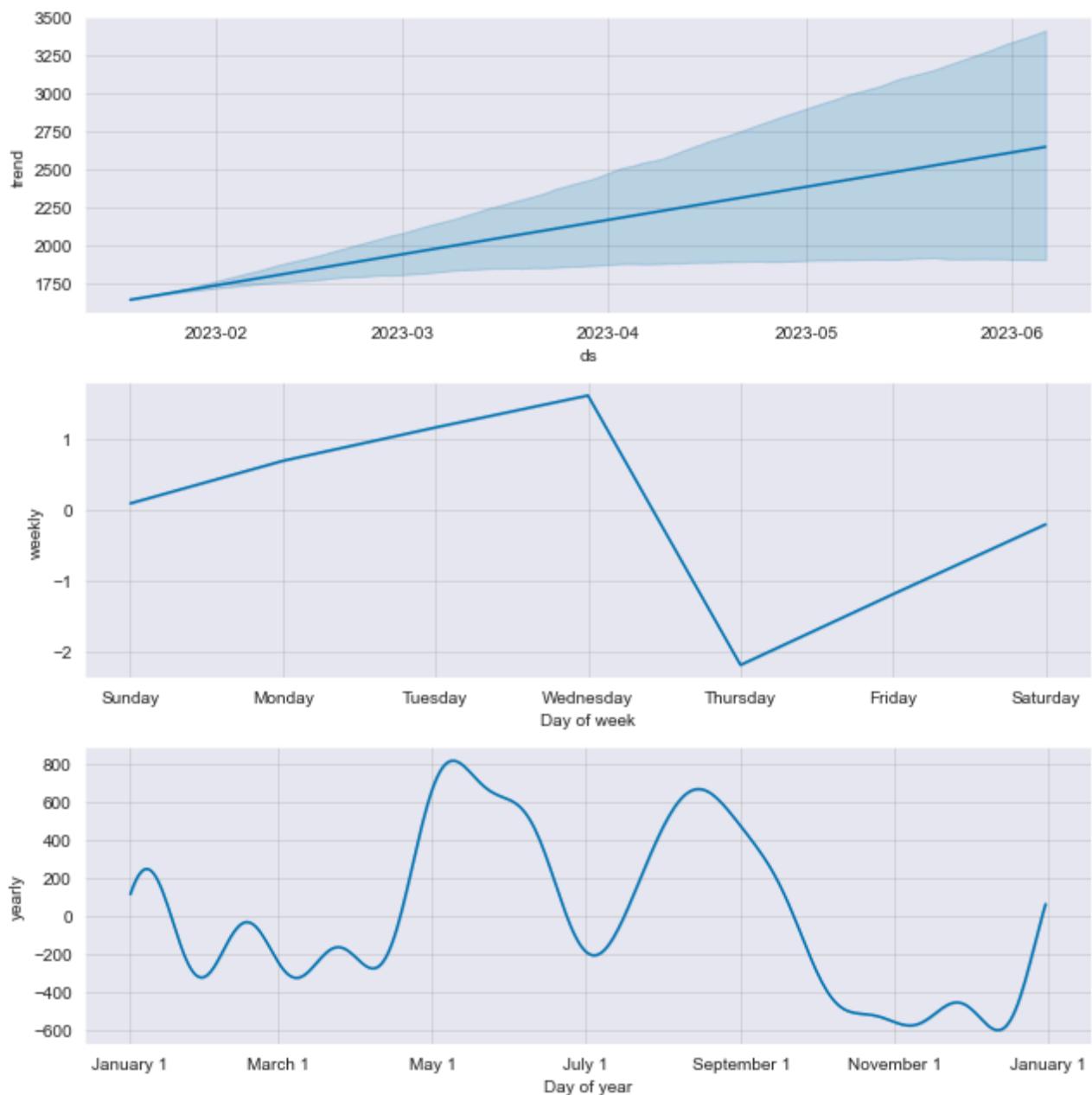
```
# Visualize predictions with uncertainty
prophet_model.plot(y_preds_prophet, uncertainty=True)
plt.show()
```



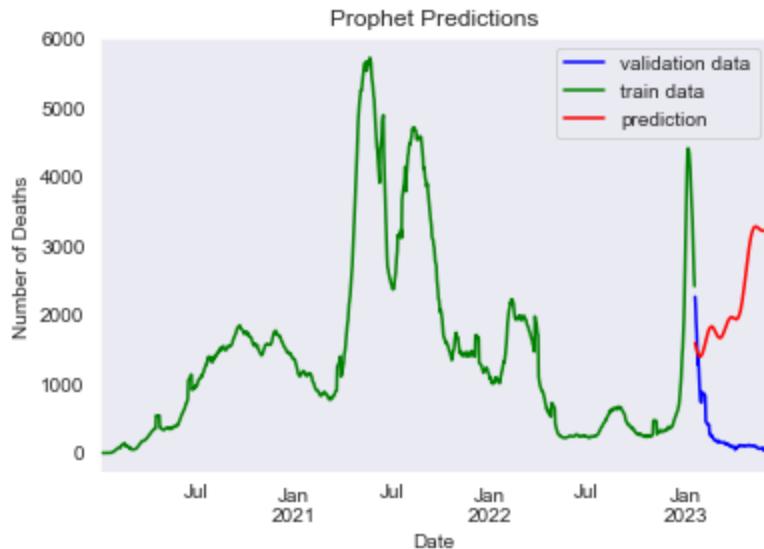
In [97]:

Visualize trends

```
prophet_model.plot_components(y_preds_prophet)
plt.show()
```



```
In [98]: # Visualize Predictions (again)  
graph_preds(y_train, y_val, y_preds_prophet['yhat'], 'Prophet')
```



```
In [99]: # evaluate  
evaluate(y_val, y_preds_prophet['yhat'], all_results, 'Prophet', np.nan)
```

```
{'model': ['Naive', 'ARIMA', 'ARIMA Multivariate', 'Linear Regression', 'Prophet'],  
'rmse': [2342.568668178121, 1943.663337601336, 968.1710140037998, 808.503557594029  
9, 2164.0648513369165], 'mae': [2305.21582733813, 1897.0728151796197, 931.239099820  
9889, 731.0303773995898, 1972.520032565029], 'train_aic': [nan, 12273.587689666143,  
12267.356533162601, 18198.26546916792, nan]}
```

Our prophet model is not doing as well as we would like, however this one was only on the time series alone (just the deaths per day data). Let's create a new prophet model with additional regressors to create a multivariate time series model -- hopefully that will improve our predictions.

Model 6 - Multivariate Prophet

Again, let's see if we can improve the model by including the other variables in our dataset.

```
In [100]: # format data
train_prophet_multi = pd.concat([train_prophet, X_train.reset_index().drop('date', a
```

Out[100]:

	ds	y	new_cases_smoothed	people_vaccinated	new_vaccinations_smoothed	stringency_index
0	2020-01-03	0.0	0.0	0.0	0.0	0.413830
1	2020-01-04	0.0	0.0	0.0	0.0	0.413830
2	2020-01-05	0.0	0.0	0.0	0.0	0.472979
3	2020-01-06	0.0	0.0	0.0	0.0	0.709362
4	2020-01-07	0.0	0.0	0.0	0.0	0.768511

```
In [101]: # create model
prophet_multi = Prophet(interval_width=0.95)
```

```
# Add Regressors for multivariate
for var in X_train.columns:
    prophet_multi.add_regressor(var, standardize=False)

# Fit Model
prophet_multi.fit(train_prophet_multi)
```

```
07:29:20 - cmdstanpy - INFO - Chain [1] start processing
07:29:20 - cmdstanpy - INFO - Chain [1] done processing
07:29:20 - cmdstanpy - ERROR - Chain [1] error: error during processing Operation not permitted
Optimization terminated abnormally. Falling back to Newton.
07:29:21 - cmdstanpy - INFO - Chain [1] start processing
07:29:29 - cmdstanpy - INFO - Chain [1] done processing
```

Out[101]: <prophet.forecaster.Prophet at 0x21c44cc7640>

```
In [102]: # Format Validation Data
val_prophet_multi = pd.concat([val_prophet[['ds']], X_val.reset_index().drop('date', a
```

Out[102]:

	ds	new_cases_smoothed	people_vaccinated	new_vaccinations_smoothed	stringency_index
0	2023-01-19	334323.430	3.661146e+09	2263131.0	0.0
1	2023-01-20	293474.715	3.661156e+09	2269036.0	0.0
2	2023-01-21	262284.714	3.661165e+09	2301769.0	0.0
3	2023-01-22	234763.715	3.661173e+09	2364924.0	0.0
4	2023-01-23	213934.002	3.661177e+09	2022023.0	0.0

In [103]:

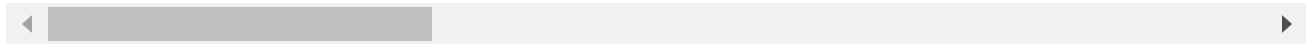
```
# predict using future dates
y_preds_prophet_multi = prophet_multi.predict(val_prophet_multi)

y_preds_prophet_multi.head()
```

Out[103]:

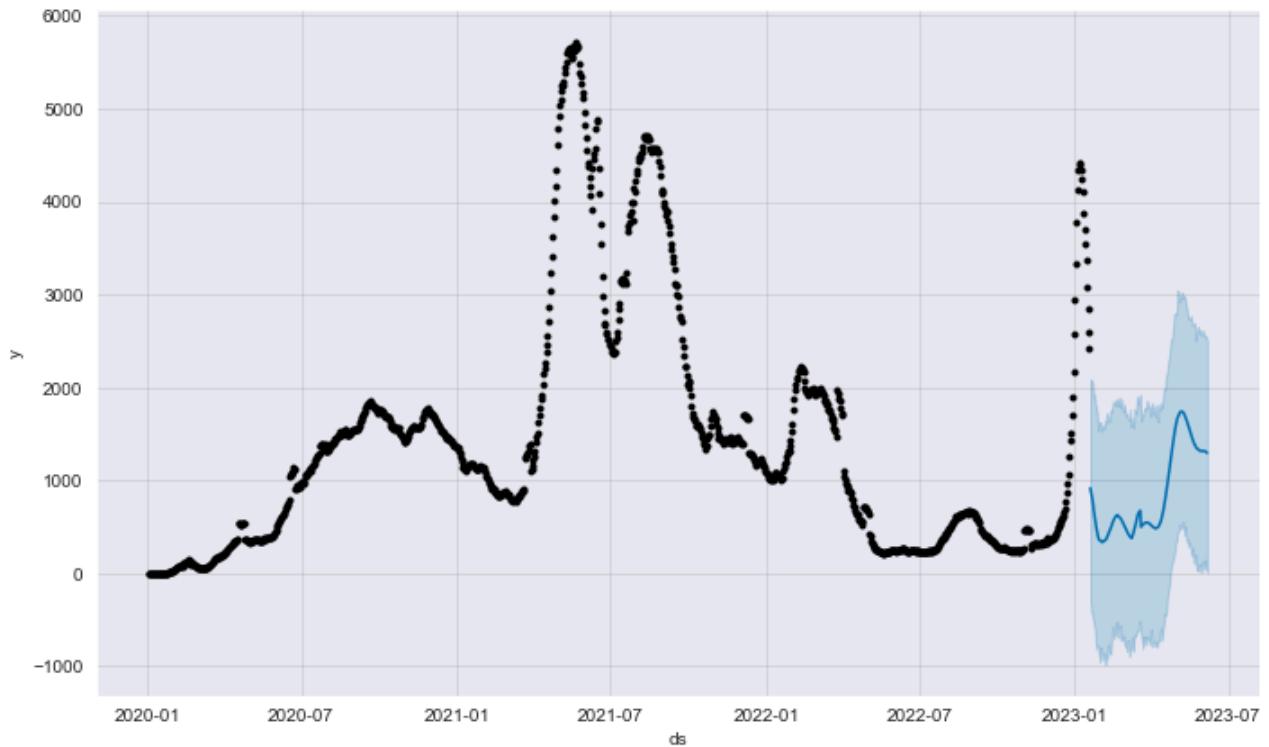
	ds	trend	yhat_lower	yhat_upper	trend_lower	trend_upper	additive_terms	additive_tern
0	2023-01-19	4640.043702	-299.957668	2086.625993	4640.043702	4640.043702	-3722.871014	-372
1	2023-01-20	4644.384588	-425.920531	2082.224649	4644.384588	4644.384588	-3780.203301	-3781
2	2023-01-21	4648.725473	-429.160163	2068.373958	4648.720948	4648.730309	-3834.801901	-383.
3	2023-01-22	4653.066359	-489.609398	2035.446564	4653.051757	4653.080831	-3886.307087	-3881
4	2023-01-23	4657.407244	-540.937384	1890.647547	4657.376208	4657.436065	-3975.433925	-397:

5 rows × 34 columns



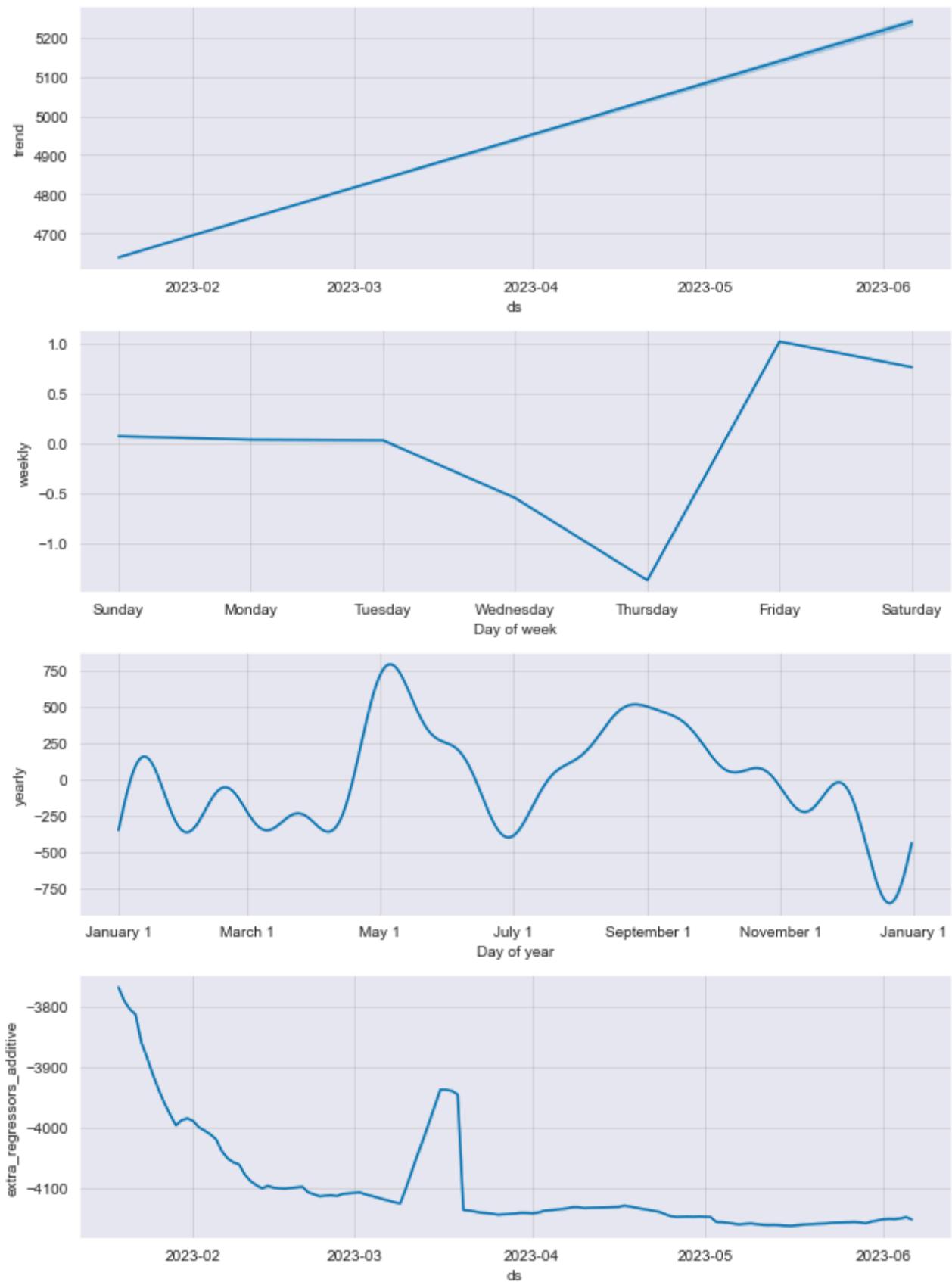
In [104]:

```
# Visualize predictions with uncertainty
prophet_multi.plot(y_preds_prophet_multi, uncertainty=True)
plt.show()
```



In [105]:

```
# Visualize Trends
prophet_multi.plot_components(y_preds_prophet_multi)
plt.show()
```

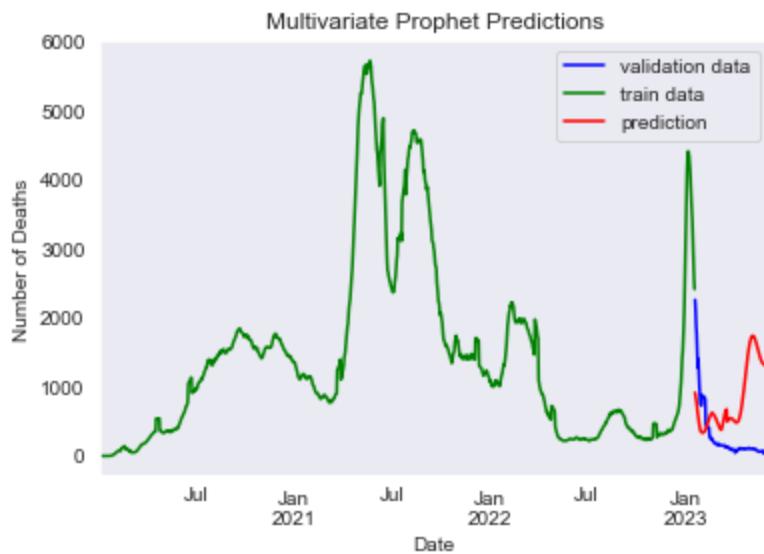


```
In [106]: # Look at regressor coefficients + intervals  
regressor_coefficients(prophet_multi)
```

Out[106]:

	regressor	regressor_mode	center	coef_lower	coef	coef_upper
0	new_cases_smoothed	additive	0.0	0.000559	0.000559	0.000559
1	people_vaccinated	additive	0.0	-0.000001	-0.000001	-0.000001
2	new_vaccinations_smoothed	additive	0.0	0.000102	0.000102	0.000102
3	stringency_index	additive	0.0	1.115817	1.115817	1.115817

```
In [107]: # Visualize predictions (again)  
graph_preds(y_train, y_val, y_preds_prophet_multi['yhat'], 'Multivariate Prophet')
```



```
In [108]: # evaluate  
evaluate(y_val, y_preds_prophet_multi['yhat'], all_results, 'Prophet Multivariate',  
{'model': ['Naive', 'ARIMA', 'ARIMA Multivariate', 'Linear Regression', 'Prophet',  
'Prophet Multivariate'], 'rmse': [2342.568668178121, 1943.663337601336, 968.1710140  
037998, 808.5035575940299, 2164.0648513369165, 904.4982723980902], 'mae': [2305.215  
82733813, 1897.0728151796197, 931.2390998209889, 731.0303773995898, 1972.5200325650  
29, 760.0219484354421], 'train_aic': [nan, 12273.587689666143, 12267.356533162601,  
18198.26546916792, nan, nan]}
```

All Model Comparison

```
In [109]: ┌─▶ all_results_df = pd.DataFrame.from_dict(all_results)
          all_results_df
```

Out[109]:

	model	rmse	mae	train_aic
0	Naive	2342.568668	2305.215827	NaN
1	ARIMA	1943.663338	1897.072815	12273.587690
2	ARIMA Multivariate	968.171014	931.239100	12267.356533
3	Linear Regression	808.503558	731.030377	18198.265469
4	Prophet	2164.064851	1972.520033	NaN
5	Prophet Multivariate	904.498272	760.021948	NaN

As we can see that all of our models that included further information, the models that did not rely solely on the number of deaths per day, had better results when forecasting. This is intuitive -- more information available generally leads to a better predictive model.

We will move forward with the Multivariate Prophet Model as our final model. While the Linear Regression model has a slightly better RMSE, it is forecasting negative values for our test dates which is unreasonable for our situation. The Multivariate Prophet model, more suited to time series, is predicting positive values.

Final Model Evaluation

Now that we have chosen our final model we can evaluate it on the hold out test set.

```
In [110]: ┌─▶ # format data
          train_all = pd.concat([train, validate])

          y_train_all = train_all[['new_deaths_smoothed']].reset_index()
          y_train_all.rename(columns={'date': 'ds', 'new_deaths_smoothed': 'y'}, inplace=True)

          X_train_all = train_all[['new_cases_smoothed', 'people_vaccinated', 'new_vaccination

          train_all_prophet = pd.concat([y_train_all,
                                         X_train_all.reset_index().drop('date', axis=1)],
                                         axis=1)
```

In [111]:

```
# Create final model
prophet_final = Prophet(interval_width=0.95)

# Add Regressors for multivariate
for var in X_train.columns:
    prophet_final.add_regressor(var, standardize=False)

# Fit Model
prophet_final.fit(train_all_prophet)
```

```
07:29:32 - cmdstanpy - INFO - Chain [1] start processing
07:29:32 - cmdstanpy - INFO - Chain [1] done processing
07:29:32 - cmdstanpy - ERROR - Chain [1] error: error during processing Operation not permitted
Optimization terminated abnormally. Falling back to Newton.
07:29:32 - cmdstanpy - INFO - Chain [1] start processing
07:29:46 - cmdstanpy - INFO - Chain [1] done processing
```

Out[111]: <prophet.forecaster.Prophet at 0x21c44df58e0>

In [112]:

```
# Format Test Data
y_test_prophet = test[['new_deaths_smoothed']].reset_index()
y_test_prophet.rename(columns={'date':'ds','new_deaths_smoothed':'y'}, inplace=True)

X_test = test[['new_cases_smoothed', 'people_vaccinated', 'new_vaccinations_smoothed']]

test_prophet = pd.concat([y_test_prophet, X_test.reset_index().drop('date', axis=1)])
test_prophet.head()
```

Out[112]:

	ds	y	new_cases_smoothed	people_vaccinated	new_vaccinations_smoothed	stringency_index
0	2023-06-07	48.427	21120.573	3.676897e+09	328635.0	0.
1	2023-06-08	48.143	19774.145	3.676899e+09	311378.0	0.
2	2023-06-09	46.859	19821.574	3.676900e+09	300382.0	0.
3	2023-06-10	45.858	22500.143	3.676901e+09	289305.0	0.
4	2023-06-11	58.002	25346.713	3.676903e+09	274783.0	0.

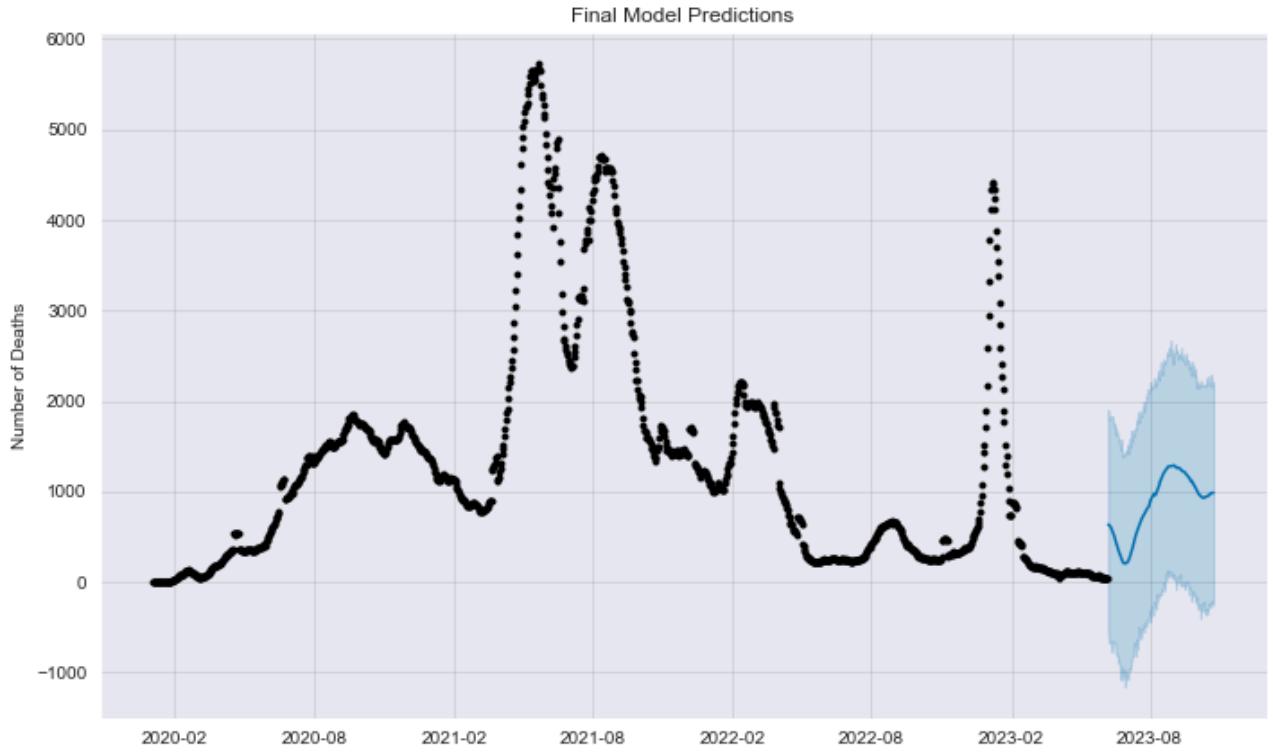


In [113]:

```
# Predict
y_preds_final = prophet_final.predict(test_prophet)
```

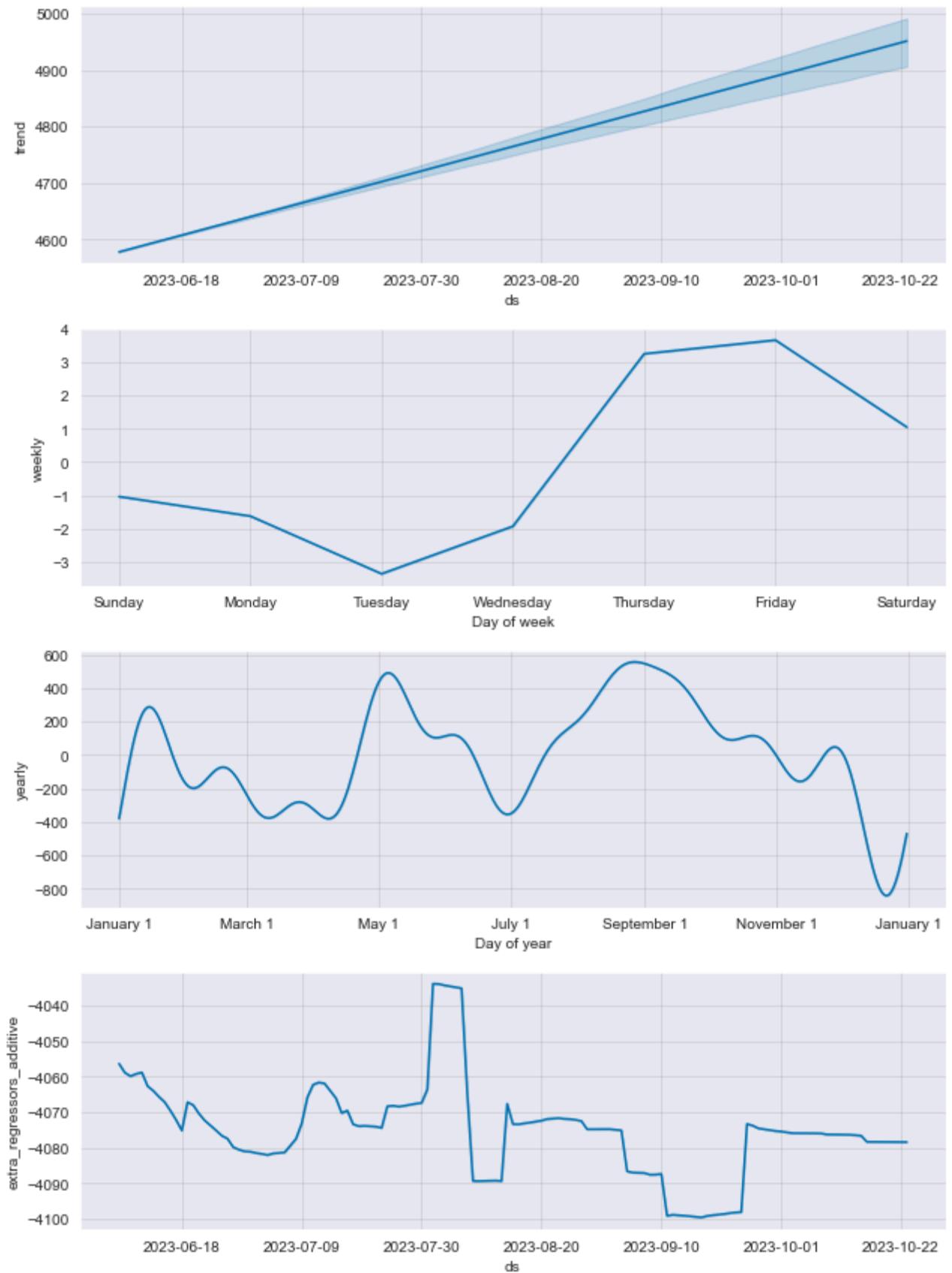
In [114]:

```
# Visualize predictions with uncertainty
prophet_final.plot(y_preds_final, uncertainty=True)
plt.title('Final Model Predictions')
plt.xlabel('')
plt.ylabel('Number of Deaths')
plt.show()
```



In [115]:

```
# Visualize trends
prophet_final.plot_components(y_preds_final)
plt.show()
```

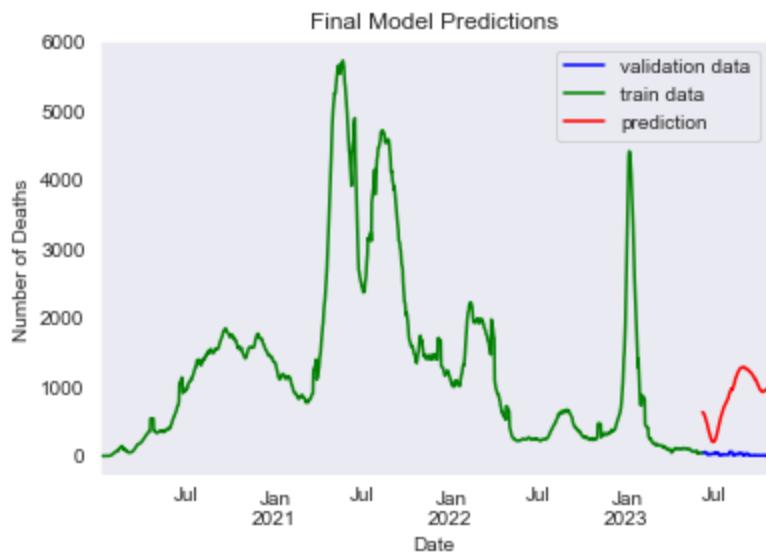


```
In [116]: # Look at regressor coefficients + intervals  
regressor_coefficients(prophet_final)
```

Out[116]:

	regressor	regressor_mode	center	coef_lower	coef	coef_upper
0	new_cases_smoothed	additive	0.0	0.000635	0.000635	0.000635
1	people_vaccinated	additive	0.0	-0.000001	-0.000001	-0.000001
2	new_vaccinations_smoothed	additive	0.0	0.000095	0.000095	0.000095
3	stringency_index	additive	0.0	1.693831	1.693831	1.693831

```
In [117]: # Visualize predictions  
graph_preds(train_all['new_deaths_smoothed'],  
            test['new_deaths_smoothed'],  
            y_preds_final['yhat'],  
            'Final Model')
```



```
In [118]: # RMSE + MAE Final  
final_rmse = mean_squared_error(test['new_deaths_smoothed'], y_preds_final['yhat'],  
final_mae = mean_absolute_error(test['new_deaths_smoothed'], y_preds_final['yhat'])  
print('Final RMSE:', round(final_rmse, 2))  
print('Final MAE:', round(final_mae, 2))
```

Final RMSE: 904.38
Final MAE: 835.69

Our model performed better on the validation data than it did on the test data. In part, this is because the pandemic had more or less ended by this time (mid 2023), which means the actual values for our data lie very close to zero, whereas our model is predicting the deaths to increase once again (similar to the actuals of July in 2020).

With an ending root mean squared error of 904 and mean absolute error of only 836, I would say this is a fairly good model, taking into account that this estimation is for the whole continent of Asia rather than one country alone.

Conclusion + Recommendations

Overall, the project completes what it set out to do. We have created a predictive time series model that will forecast the number of deaths that will occur in the near future. Having such a model, especially one that takes into consideration factors such as the stringency index which directly relates to the public health policies currently put in place, can be very useful to public health officials. With this information they can work on when to ramp up or ease off public health ordinances such as mask mandates and social distancing.

The recommendations for the business are as follows:

1. **Utilize the model to advise public health officials.** Once we have forecasting the amount of harm predicted, we can then advise public health officials on what actions to take concerning public health measures such as mask mandates, social distancing, and stay-at-home orders (either to make more strict or lessen).
2. **Utilize the model to aid in resource planning.** From our forecasts of when spikes will occur, we can make recommendations to vendors and hospitals concerning resource planning.
3. **Investigate why deaths tend to be reported higher on Fridays.** From our final model, we can see a weekly trend where reported number of deaths is generally higher on Fridays by about 4 people, and lower earlier in the week by about 3 people. While a slight trend, it would be interesting to investigate why this is; if it is anything in the hospitals systems or public health trends that can be addressed in such a way that number of deaths lessens.

Next Steps

There is always more to do and try! Below are some ideas for expanding on this project:

- Continue to make data more accurate and complete
 - The missing, purposefully mis-reported, and unusable data all made our model less accurate than it could have been. Looking for ways in the future to gain accurate, consistent data, as well as ways to utilize the 'constants' would be beneficial in future model endeavors.
- Data by continent
 - compare predictive models by continent
 - compare how well each continent handled the pandemic
- Data by country
 - create regressive model that can predict number of deaths based on location (and other variables that were in dataset) *Not Time Series*
 - Time series by country and then create a user interface to choose country and date to forecast and then predicts number of deaths