新冠病毒数据分析系列公益讲座
COVID-19 Data Analysis Webinars

COVID19
Spatiotemporal Analysis and Prediction
Based on Workflow Platform
基于工作流的疫情数据时空预测模型与统计分析

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China Data Lab

GRoNC Global Research on Novel Coronavirus
http://chinadatalab.org/

HARVARD
Dataverse

BACKGROUND

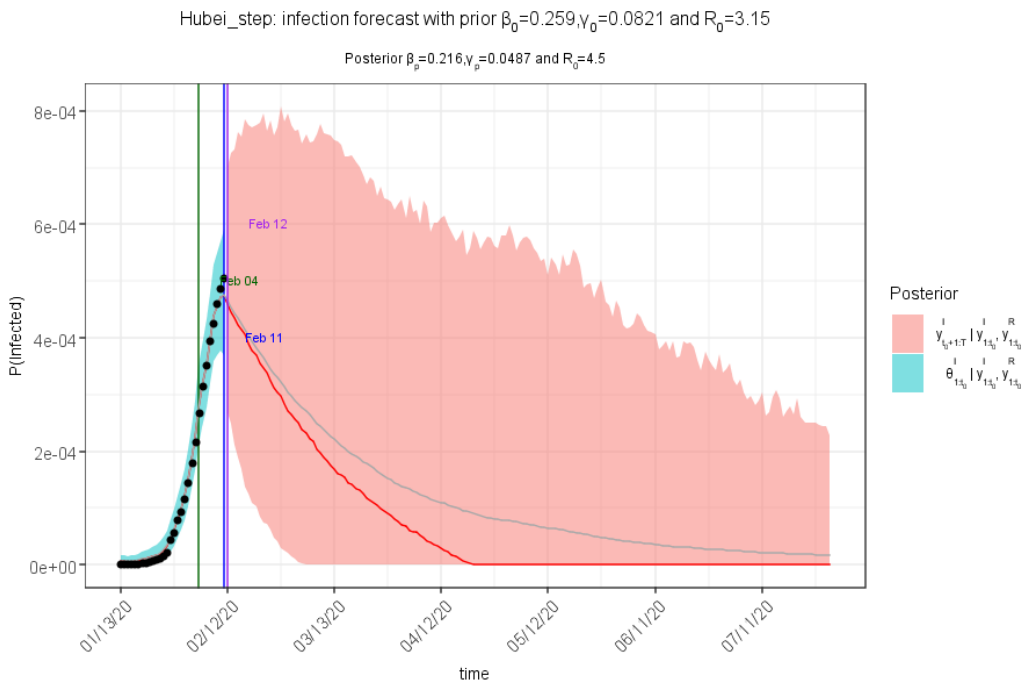
Time Varying Transmission Rate in SIR

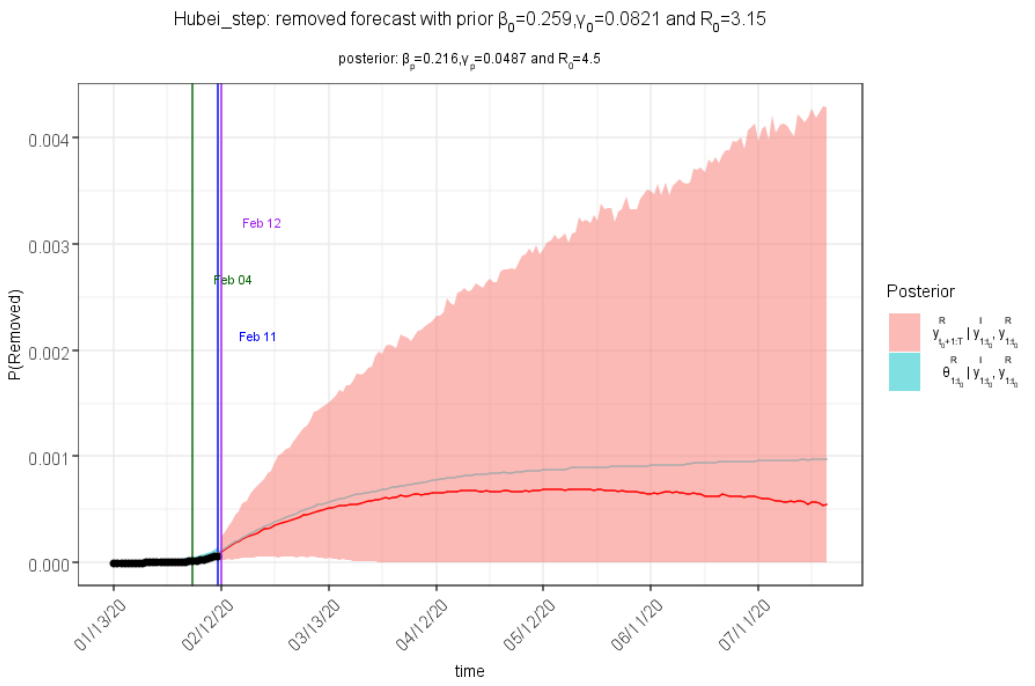
SIR model: eSIR packages in R

Song Lab
Department of Biostatistics

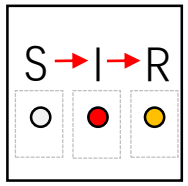
SCHOOL OF PUBLIC HEALTH
UNIVERSITY OF MICHIGAN

https://github.com/lilywang1988/eSIR

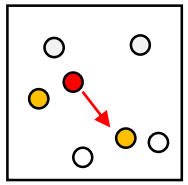




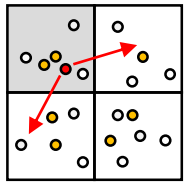
BACKGROUND



SIR Model



Spatial Contact



Neighborhood Effect

Spatial contact : the transmission of Epidemic diseases

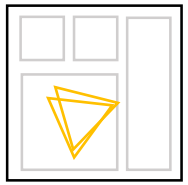
Spatial contact chance(SCC) influence the transmission rate of COVID19

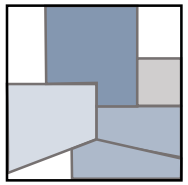
- Basic SIR model lack parameters representing the changes of spatial contact
- Basic SIR model ignore the spatial influence of adjacent areas

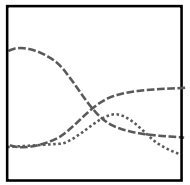
- Investigate the spatial effect of COVID19
- Integrating the parameters affecting spatial contact chance
- Building a opensource workflow for COVID19 researches

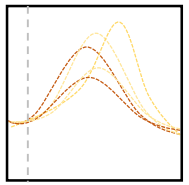
OBJECTIVES

KNIME Workflow Platform
COVID19 Spatiotemporal Analysis


KNIME


Spatial Effect


SIR Model

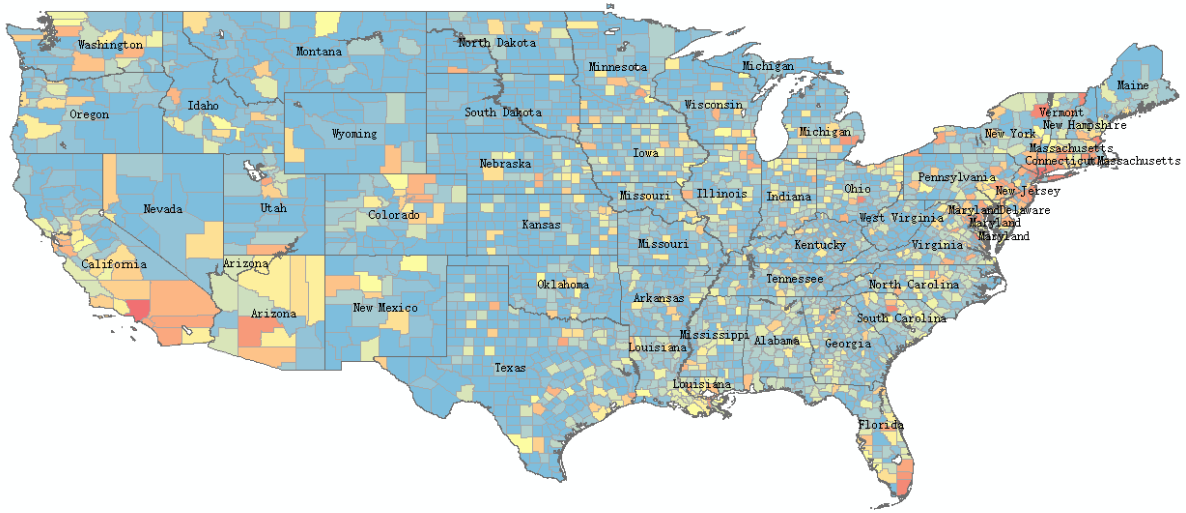

Spatial SIR

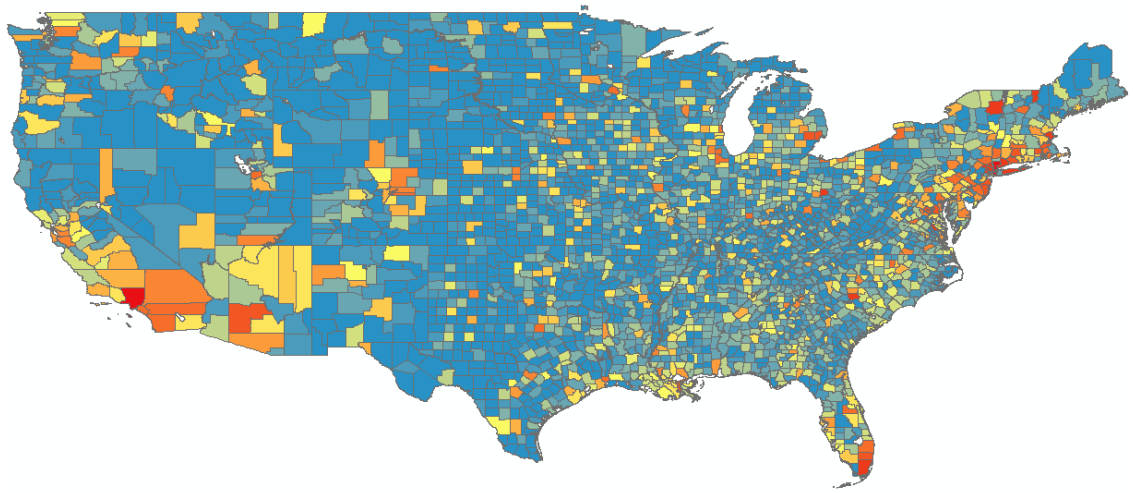
- Building COVID19 dashboard with KNIME component layout
- Spatial autocorrelation analysis with KNIME R extension
- Modelling COVID19 with SIR and Logistic Growth Model
- Spatial Panel Model integrated with SIR

DATA

- COVID19 data from nCov2019 package
- COVID19 data of Continental America (County level)

https://dataverse.harvard.edu/dataverse/cdl_dataverse

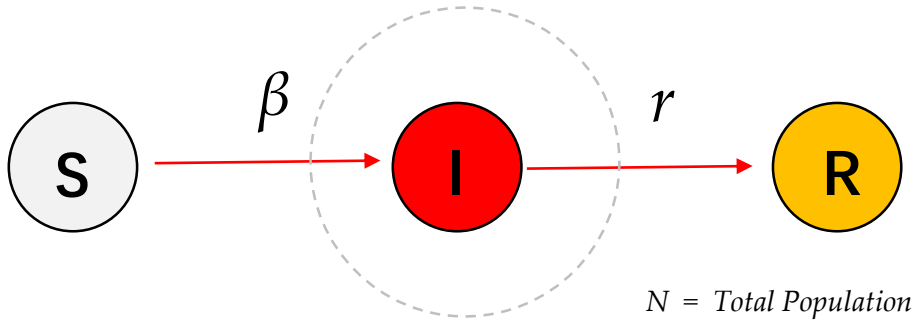




METHODOLOGY

- **Basic SIR model**

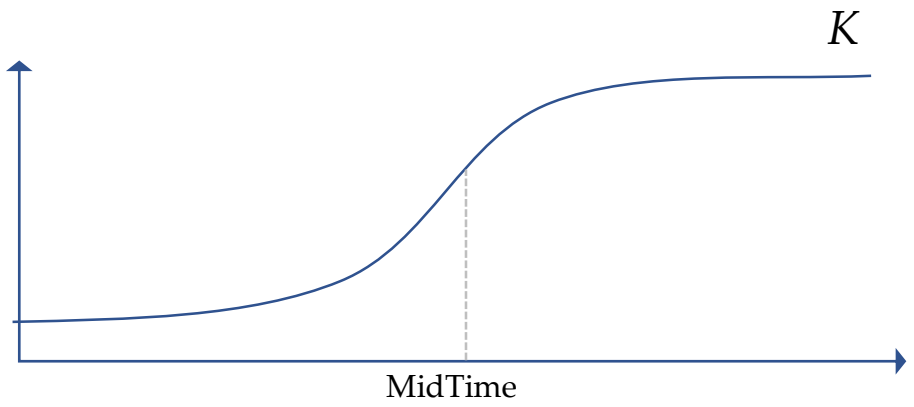
$$N = S + I + R$$
$$dS = -\beta * S * I/N$$
$$dI = \beta * S * I/N - r * I$$
$$dR = r * I$$



N = *Total Population*
S = *Susceptible population*
I = *Infected population*
R = *Removed (Recover/ Death)*

- **Logistic growth model**

$$I = K * \frac{1}{1 + e^{\frac{\text{MidTime} - t}{Scale}}}$$



METHODOLOGY

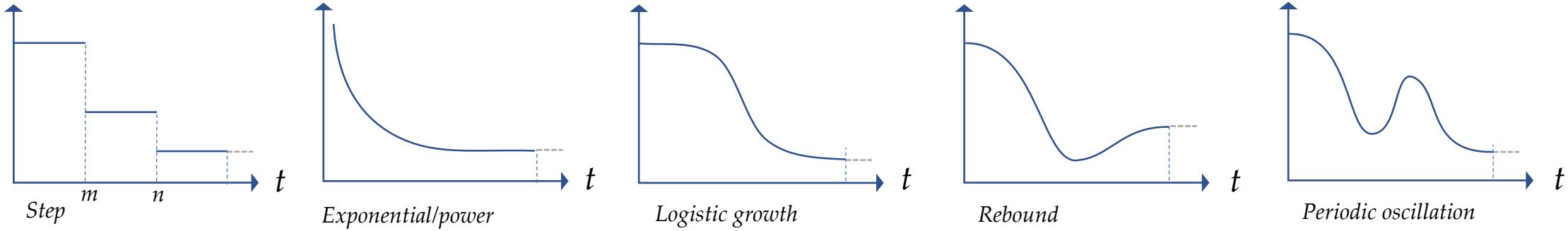
- **SIR model with time-varying SCC** $dS = -\beta SI/N$ $\beta = f(t) * \beta_0$

$$f(t) = \begin{cases} a & 0 < t < m \\ b & m < t < n \\ c & t > n \end{cases}$$

$$f(t) = K_0 * a^t$$

$$f(t) = K_0 * t^a$$

$$f(t) = K_0 * \frac{1}{1+e^{\frac{X-t}{a}}}$$

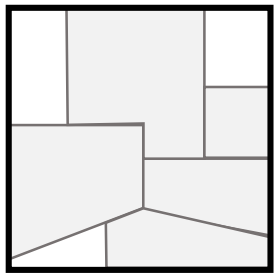


eSIR： *tvt.eSIR / qh .eSIR*

Possible function of f(t)

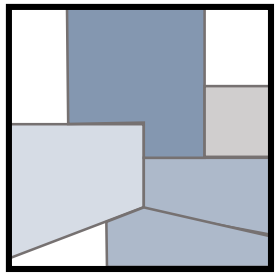
METHODOLOGY

- **Spatial Correlation**



- Moran'I

Global Spatial Statistics



- Local Moran'I

Local Spatial Statistics
LISA local Indicators of Spatial Autocorrelation

$$I(d) = \frac{\sum_{i}^{n}\sum_{j\neq i}^{n} w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{S^2 \sum_{i}^{n}\sum_{j\neq i}^{n} w_{ij}}$$

$$I_i(d) = Z_i \sum_{j\neq i}^{n} w_{ij} Z_j$$

DATA ANALYSIS

- **SIR integrated with Spatial Correlation**

$$y = \alpha X + \varepsilon$$

Spatial Panel model $y = \rho \Sigma y + \theta Wx + \alpha X + \varepsilon \quad \varepsilon = \lambda Wx + \mu$

SLM $y = \rho \Sigma y + \alpha X + \varepsilon$

SEM $y = \alpha X + \varepsilon \quad \varepsilon = \lambda Wx + \mu$

SDM $y = \rho \Sigma y + \theta Wx + \alpha X + \varepsilon$

dI_i *(Daily new cases in Zone I)* $= \beta_i S_i I_i / N_i$

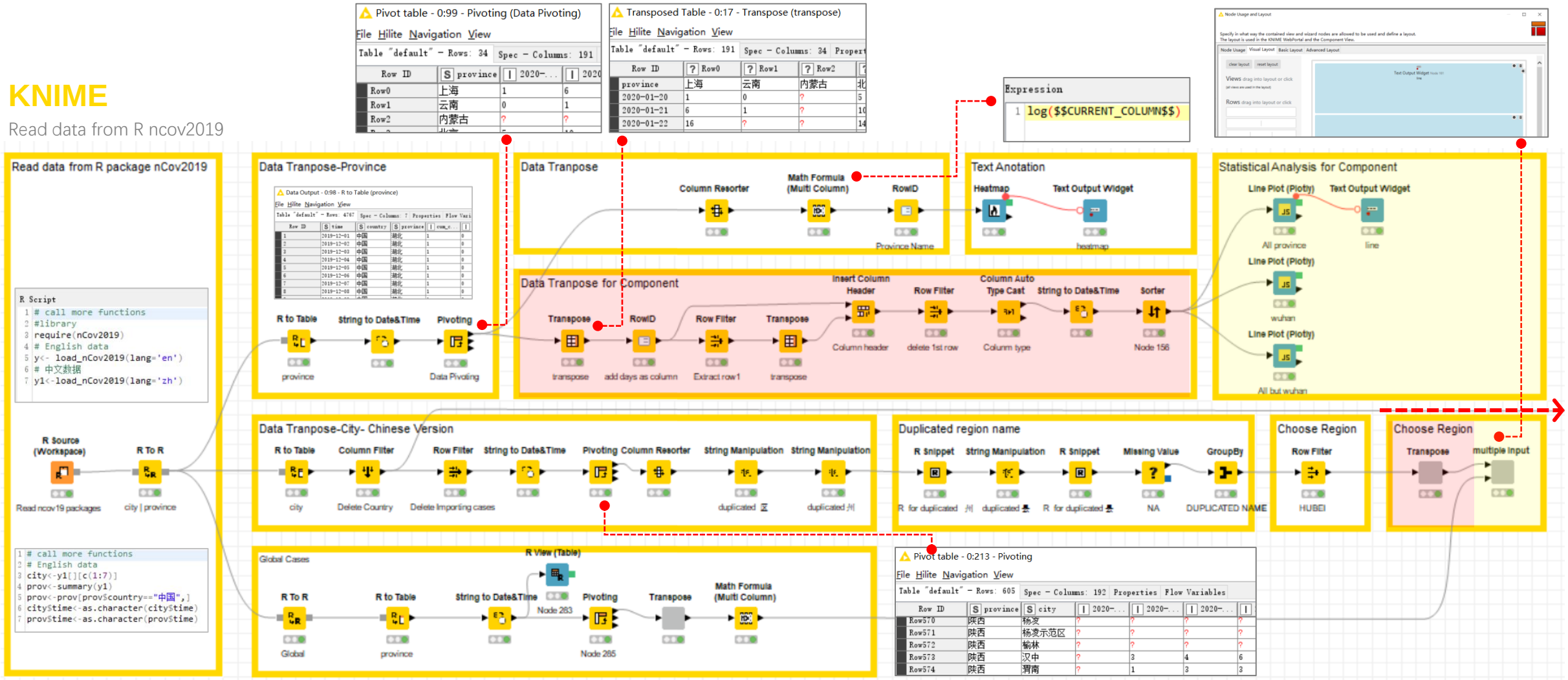
$y = \beta x_1 + r x_2$

$y = dI_i \qquad x_1 = S_i I_i / N_i$

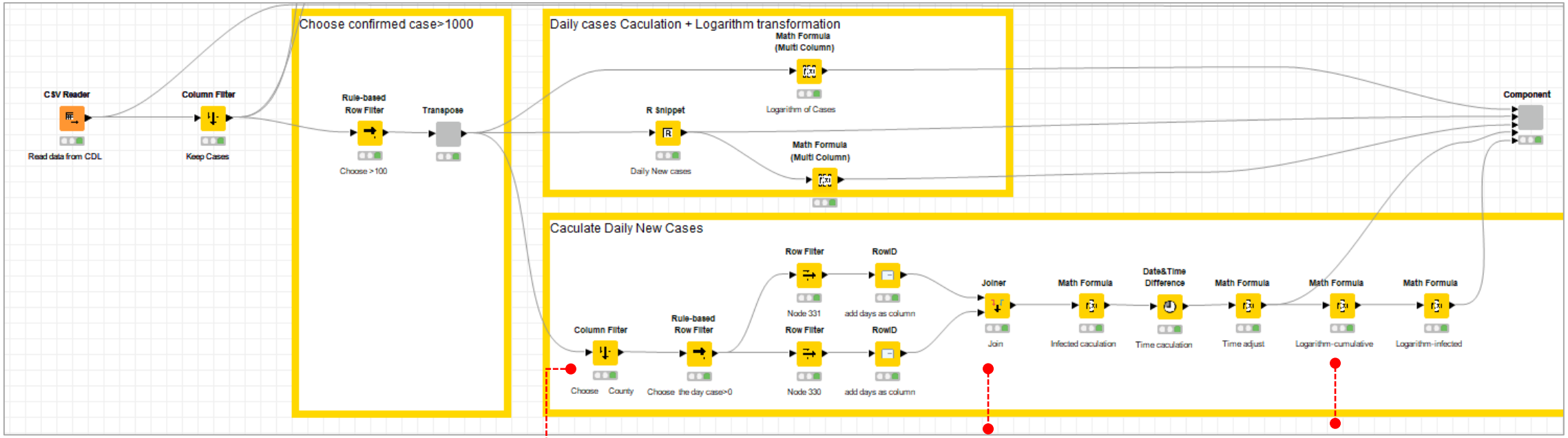
RESULTS COVID19 DASHBOARD WITH KNIME

KNIME

Read data from R ncov2019



RESULTS COVID19 DASHBOARD WITH KNIME



KNIME

Read data from CSC reader

Filtered - 0:328 - Rule-based Row Filter

File Hilite Navigation View

Table "default" – Rows: 60 Spec – Columns

Row ID	Milwa...	day
Row52	2	2020-03-13
Row53	6	2020-03-14
Row54	7	2020-03-15
Row55	13	2020-03-16
Row56	24	2020-03-17

Row ID	Milwa...	day	Milwa...	day (#1)
Row0	6	2020-03-14	2	2020-03-13
Row1	7	2020-03-15	6	2020-03-14
Row2	13	2020-03-16	7	2020-03-15
Row3	24	2020-03-17	13	2020-03-16
Row4	47	2020-03-18	24	2020-03-17
Row5	62	2020-03-19	47	2020-03-18
Row6	85	2020-03-20	62	2020-03-19
Row7	126	2020-03-21	85	2020-03-20
Row8	182	2020-03-22	126	2020-03-21
Row9	204	2020-03-23	182	2020-03-22

log(x)

Expression

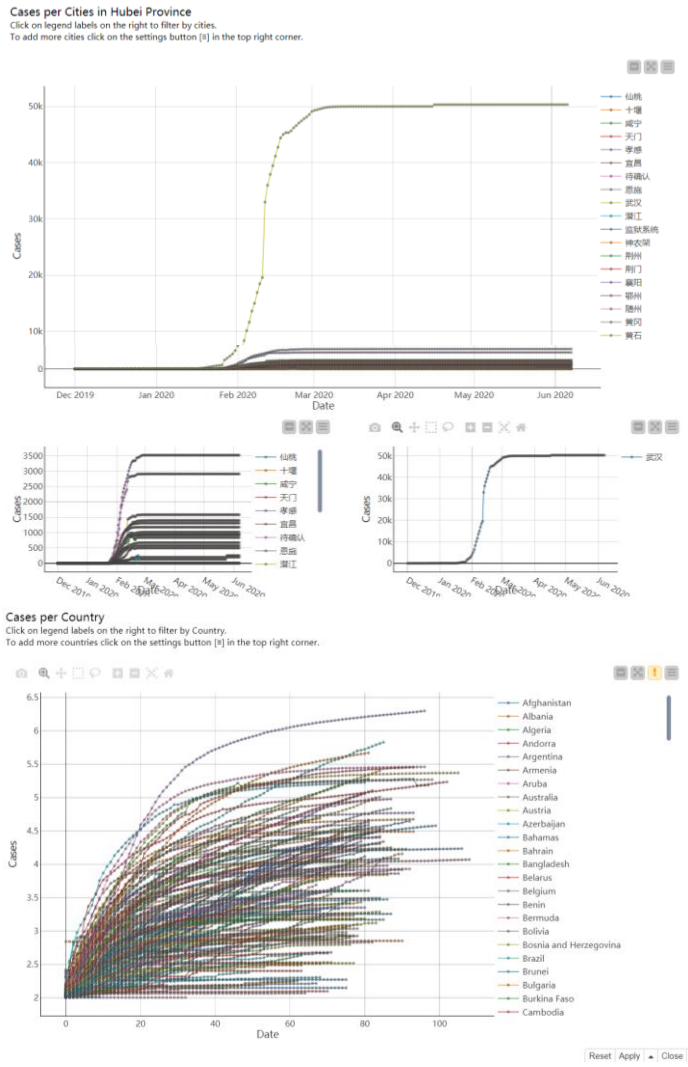
```
ln($Milwaukee County$)
```

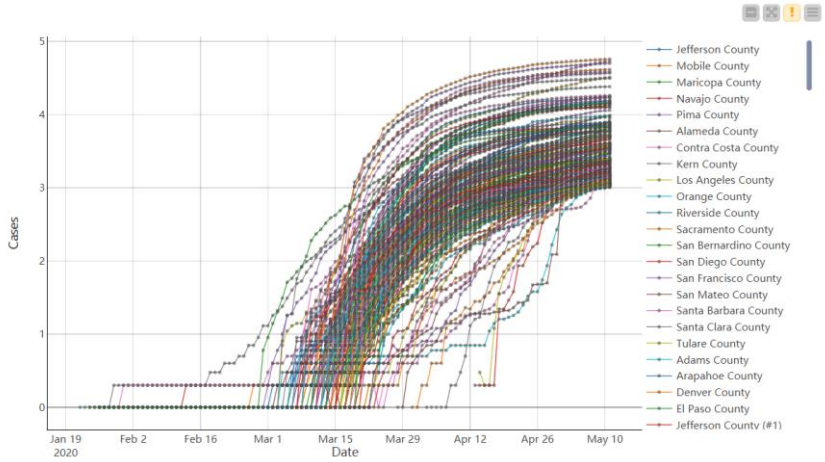
Append Column:

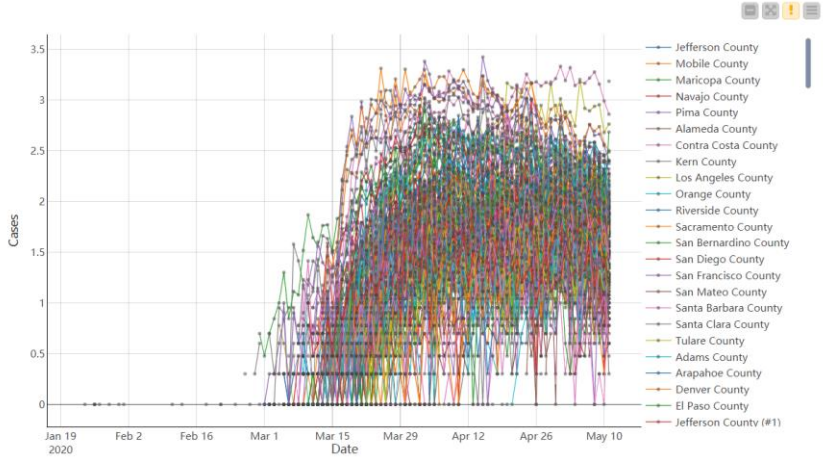
Replace Column: Milwaukee County

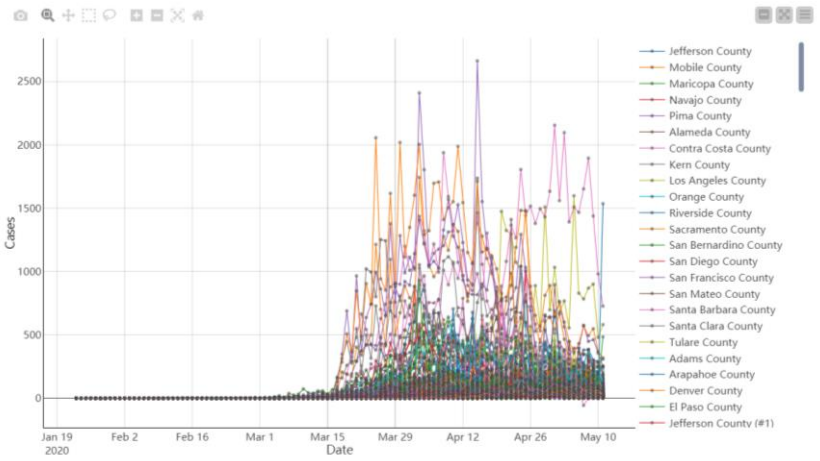
Convert to Int

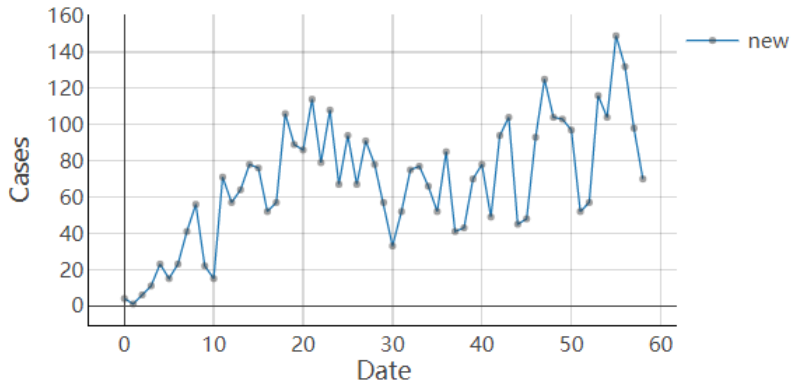
RESULTS COVID19 DASHBOARD WITH KNIME



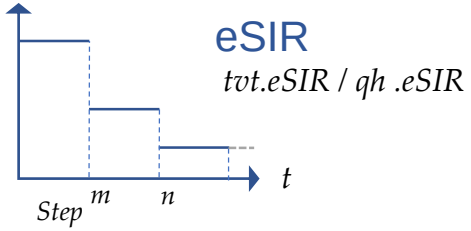




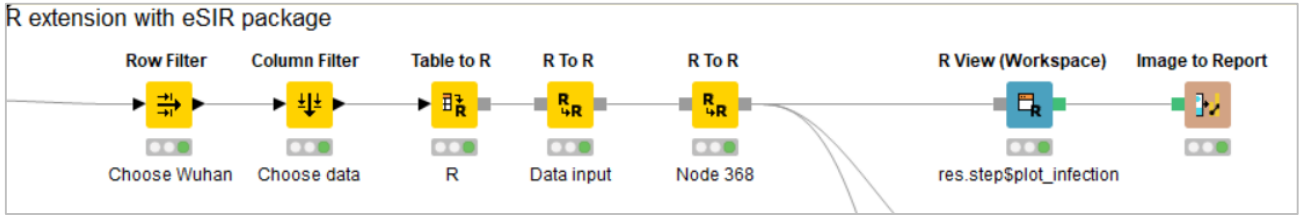


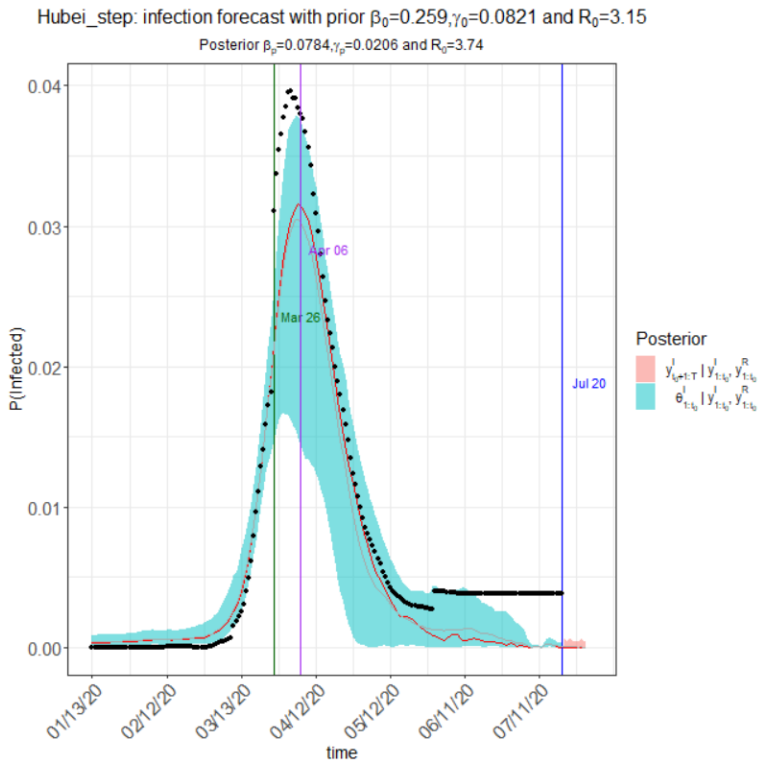


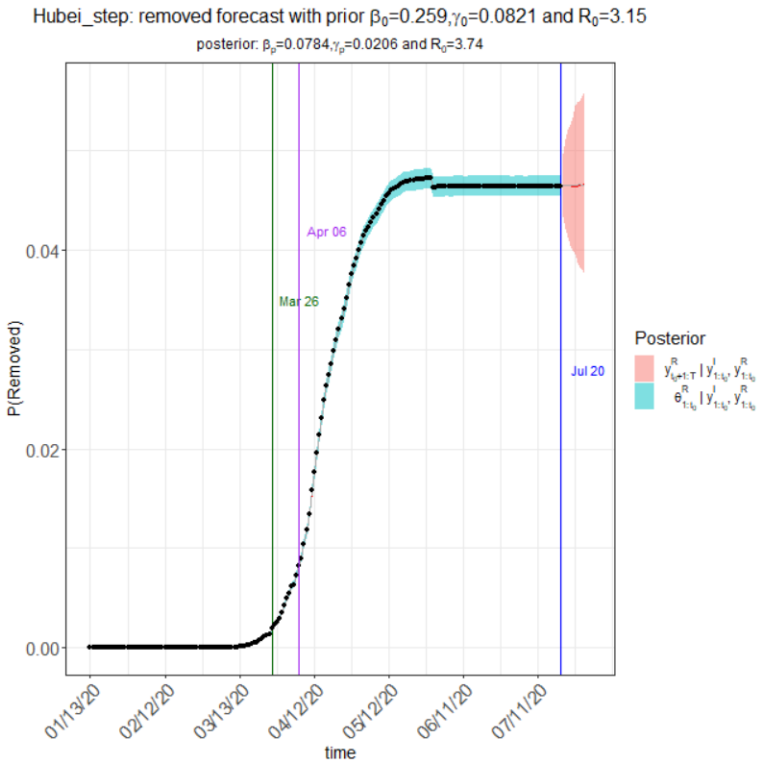
RESULTS eSIR MODELLING

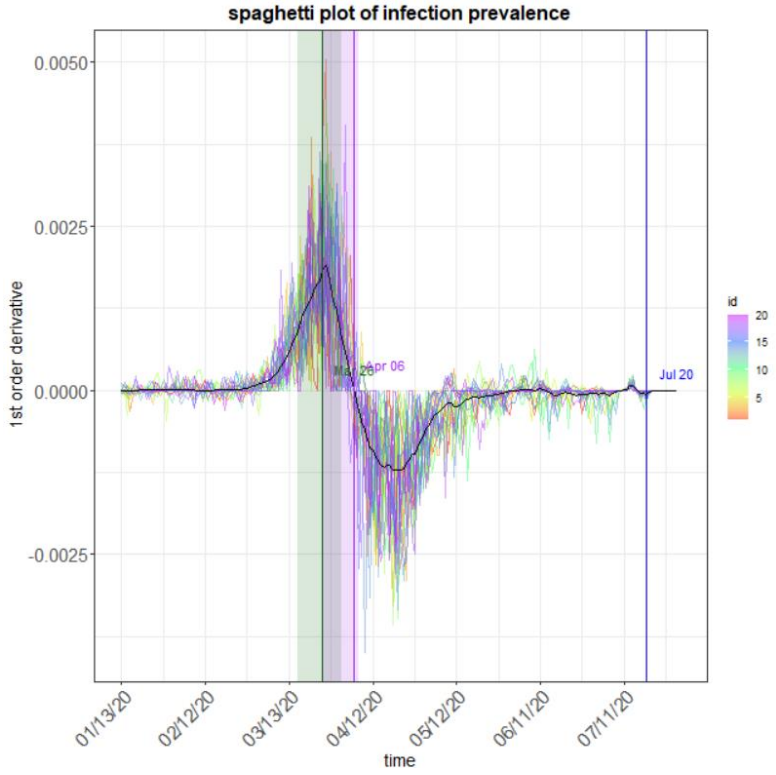


KNIME



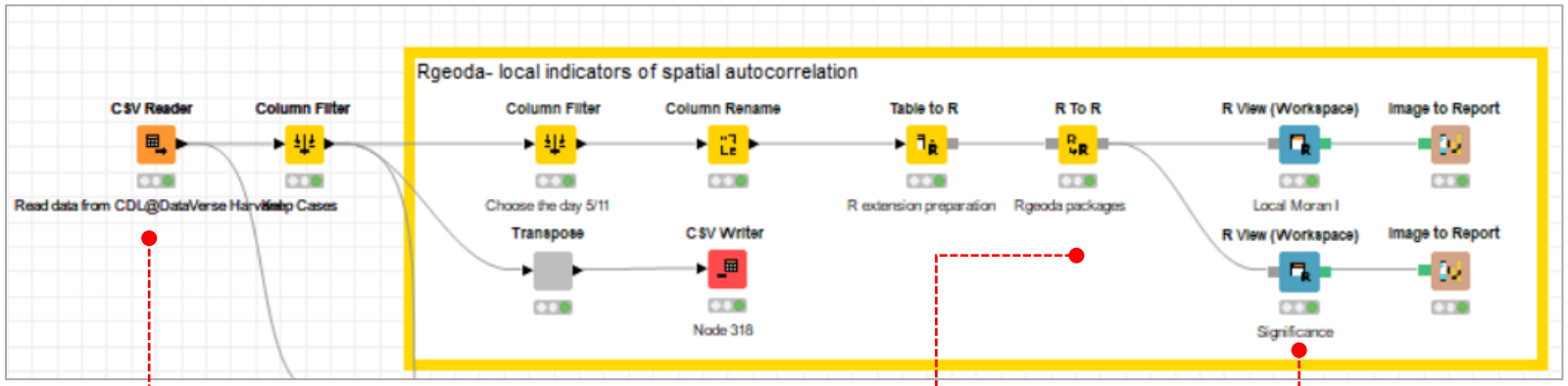


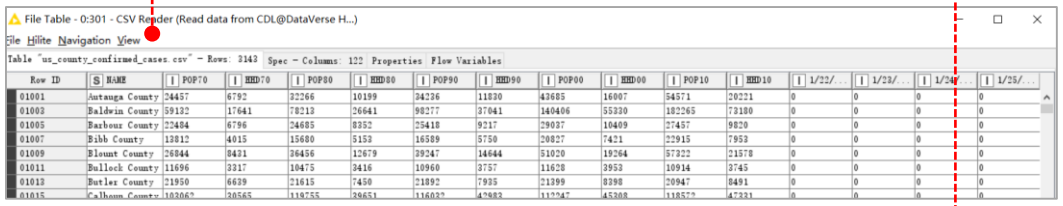




RESULTS

LOCAL MORAN'S I OF CONFIRMED CASES





R Script

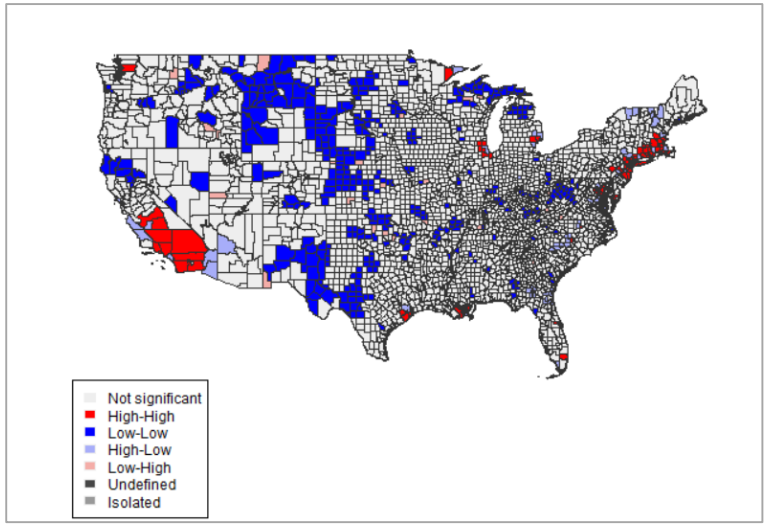
```
# call more functions
library(rgdal)
library(rgeoda)
library(sf)

county_sf <- st_read("D:/CDL/dataverse/UScounty/COUNTY_MAP/countytest.shp")
county_sf<-merge(county_sf,df,all.x=TRUE)
county <- sf_to_geoda(county_sf, with_table = TRUE)
county0w <- queen_weights(county)

Confirm <- county_sf$Confirm
lisa <- local_moran(county0w, Confirm)
lisa_colors <- lisa$GetColors()
lisa_labels <- lisa$GetLabels()
lisa_clusters <- lisa$GetClusterIndicators()
lisa_p <- lisa$GetPValues()
```

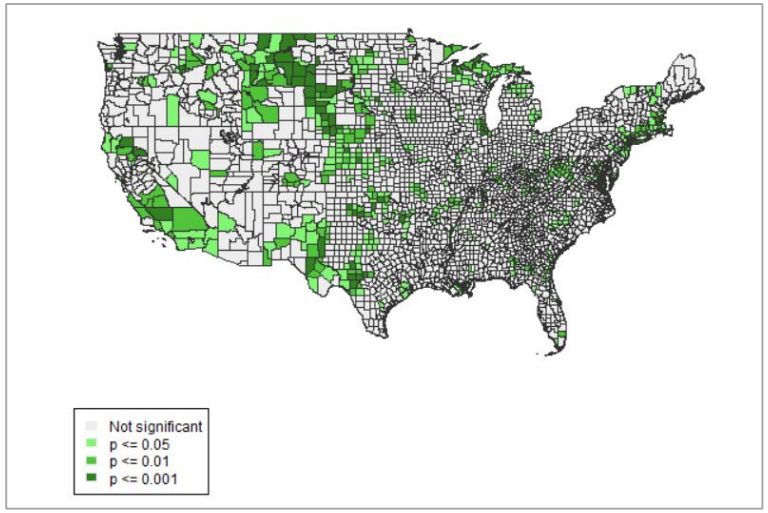
R Script

```
plot(st_geometry(county_sf),
     col=sapply(lisa_clusters, function(
     border = "#333333", lwd=0.2)
title(main = "Local Moran Map of COVID19
legend('bottomleft', legend = lisa_label
```

R Script

```
p_labels <- c("Not significant", "
p_colors <- c("#eeeeee", "#84f576"
plot(st_geometry(county_sf),
     col=sapply(lisa_p, function(x
       if (x <= 0.001) return(p_co
       else if (x <= 0.01) return(
       else if (x <= 0.05) return
       else return(p_colors[1])
       }),
     border = "#333333", lwd=0.2)
```

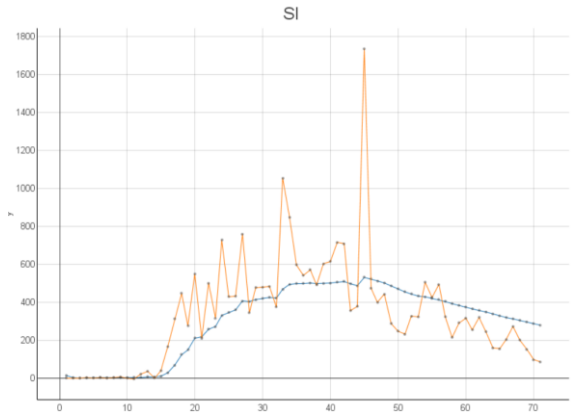


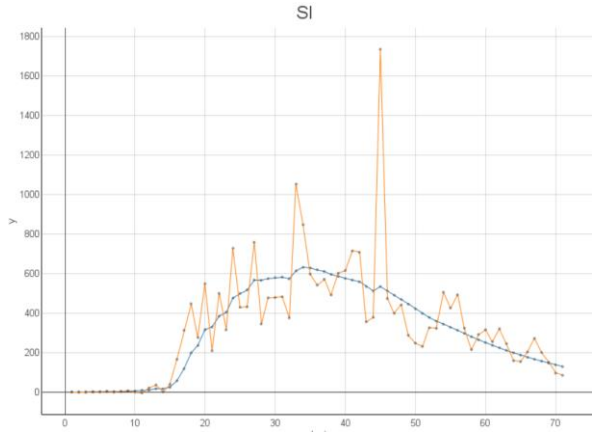


RESULTS SIR WITH TIME VARYING SCC

$$dS = \beta SI/N \quad \beta = f(t)^* \beta_0$$

$$Ln(dS) = Ln\beta_0 + ln(SI/N) + ln\, f(t)$$





Linear Re...

File

Statistics on Linear Regression

Variable	Coeff.	Std. Err.	t-value	P>|t|
INS	0.635	0.0386	16.4442	0.0
Intercept	-0.0425	0.3208	-0.1326	0.8949

Multiple R-Squared: 0.7967
Adjusted R-Squared: 0.7938

$$f(t) = \beta_0$$

Linear Re...

File

Statistics on Linear Regression

Variable	Coeff.	Std. Err.	t-value	P>|t|
dayt	-2.492	0.4017	-6.204	3.73E-8
INS	1.3568	0.1204	11.2666	0.0
Intercept	2.6083	0.4992	5.2246	1.81E-6

Multiple R-Squared: 0.8702
Adjusted R-Squared: 0.8664

$$f(t) = \beta_0 * t^{a}$$

Linear Regr...

File

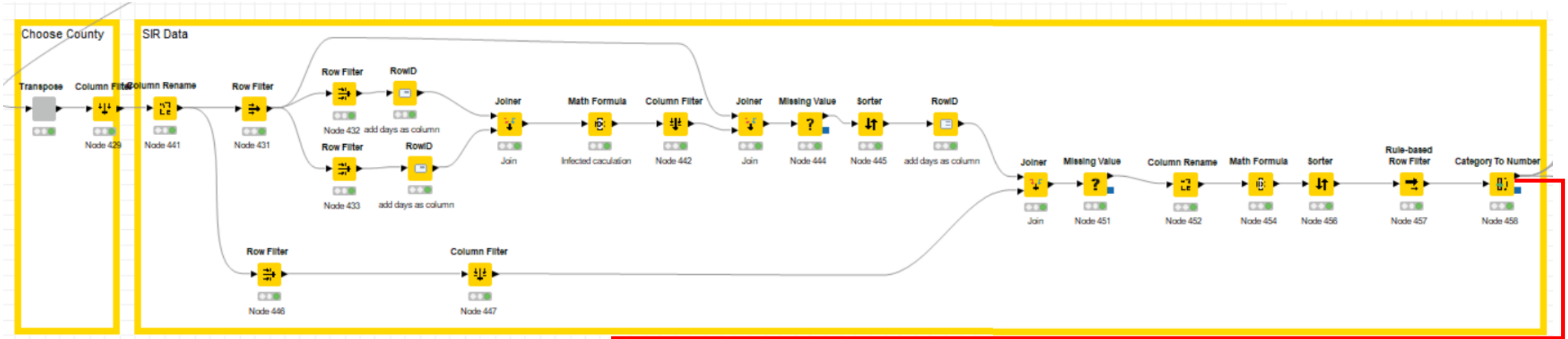
Statistics on Linear Regression

Variable	Coeff.	Std. Err.	t-value	P>|t|
dayt	-0.0691	0.0074	-9.3095	9.35E-14
INS	1.0384	0.0504	20.5921	0.0
Intercept	-0.6779	0.2249	-3.0146	0.0036

Multiple R-Squared: 0.9106
Adjusted R-Squared: 0.908

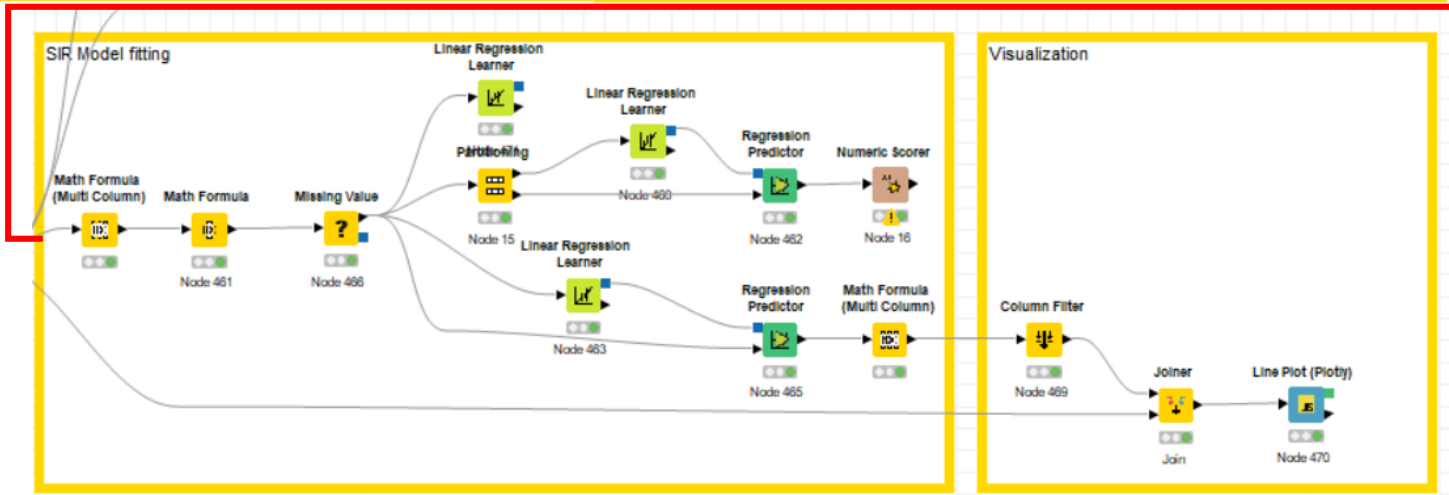
$$f(t) = \beta_0 * a^{t}$$

RESULTS SIR WITH TIME VARYING SCC

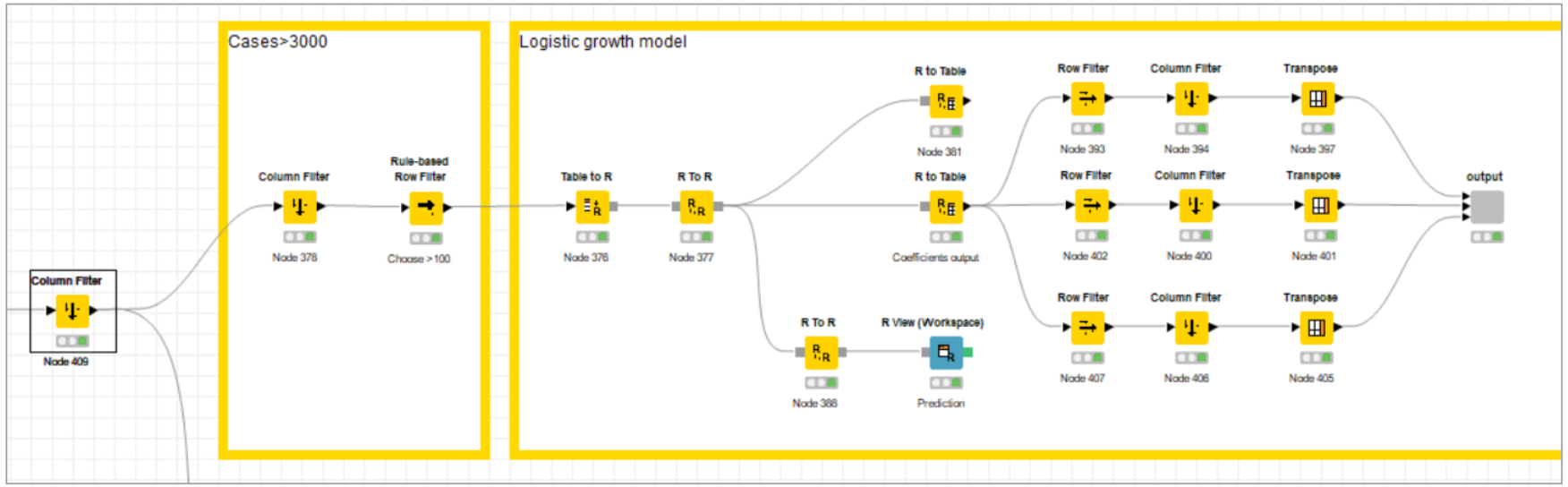


Queen...	Richm...	Rockl...	Schen...	day
80117	165516	99242	62886	1/10
0	0	0	0	1/22/2020
0	0	0	0	1/23/2020
0	0	0	0	1/24/2020
0	0	0	0	1/25/2020
0	0	0	0	1/26/2020
0	0	0	0	1/27/2020
0	0	0	0	1/28/2020
0	0	0	0	1/29/2020
0	0	0	0	1/30/2020
0	0	0	0	1/31/2020
0	0	0	0	2/1/2020
0	0	0	0	2/2/2020

Row ID	County	day	new
Row70_Row67	6060	3/30/2020	478
Row71_Row68	6539	3/31/2020	479
Row72_Row69	7022	4/1/2020	483
Row73_Row70	7398	4/2/2020	376
Row74_Row71	8452	4/3/2020	1,054
Row75_Row72	9300	4/4/2020	848
Row76_Row73	9898	4/5/2020	598
Row77_Row74	10440	4/6/2020	542
Row78_Row75	11012	4/7/2020	572
Row79_Row76	11504	4/8/2020	492
Row80_Row77	12106	4/9/2020	602
Row81_Row78	12722	4/10/2020	616
Row82_Row79	13437	4/11/2020	715
Row83_Row80	14145	4/12/2020	708



RESULTS LOGISTIC GROWTH MODEL

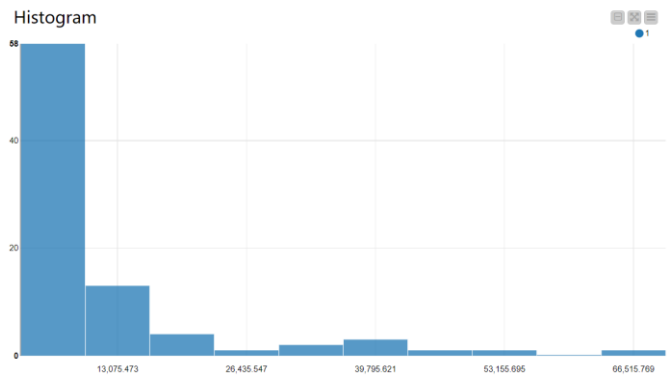


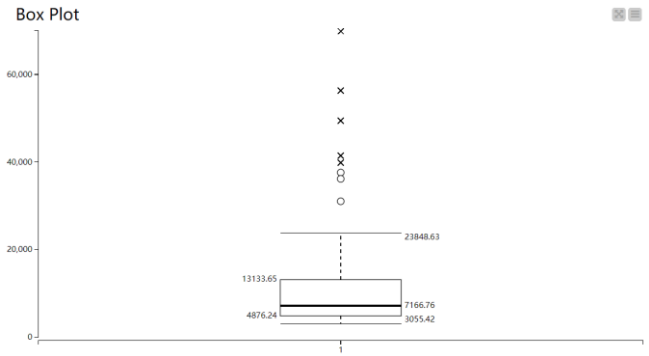
time	Maric...	t1	Los A...	t2	Orang...	t3	River...	t4	San B...	t5	
1	5.17	5	8.042	5	3.925	5	31.24	47	64.576	54	1
2	5.589	6	8.828	6	4.236	6	35.252	48	71.012	55	1
3	6.043	7	9.692	7	4.572	7	39.775	49	78.075	56	2
4	6.533	8	10.641	8	4.935	8	44.874	50	85.821	57	2
5	7.062	9	11.682	9	5.326	9	50.62	51	94.314	58	2
6	7.635	10	12.825	10	5.748	10	57.093	52	103.621	59	2
7	8.254	11	14.08	11	6.203	11	64.384	53	113.814	60	2

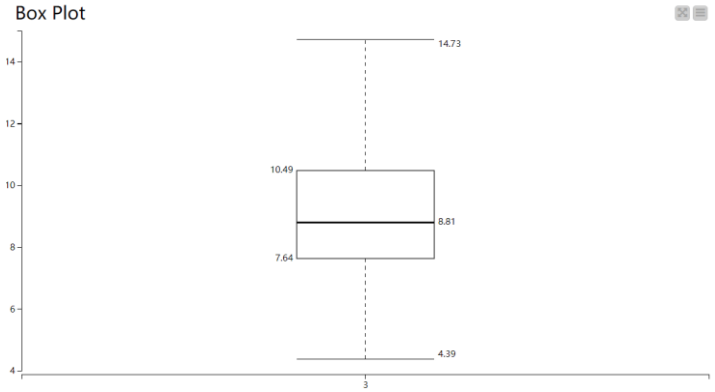
R Script

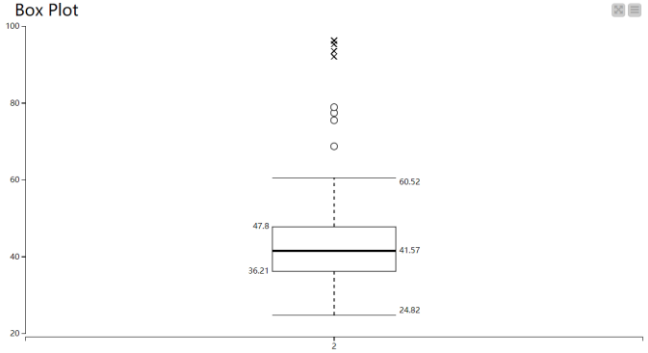
```r
# delete
dataf<-dataf[-41,]
library(broom)
library(tidyr)
library(dplyr)
tt<-300
x2<-1:tt
data0<-data.frame(time=x2)
result<-data.frame(term=c("a","b","c","d"))
nm<-length(dataf[,1])
for (i in 1:nm){
     n<-i
     x<-dataf[n,]
     xt<-t(x)
     xt<-xt[-1,]
     xt<-subset(xt,xt!=0)
     xt<-as.data.frame(xt)
     IDL<-length(xt[,1])
     xt$ID<-1:IDL
     T0<-length(x)-IDL-1
     xt$xt<-as.numeric(as.character(xt$xt))
     lm1 <- nls(xt ~ SSlogis(ID, a, b,c),data=xt)
     y2<-predict(lm1,newdata = data.frame(ID= x2))
     newdata<-data.frame(y=y2,time=x2)
     Name<-x$NAME[1]
     names(newdata)[1]<-as.character(Name)
     newdata$t<-newdata$time+T0
     data0<-merge(data0,newdata,by="time")
     res<-tidy(lm1)
     names(res)[5]<-paste(Name,sep="")
     result<-merge(result,res,by="term")
}
```

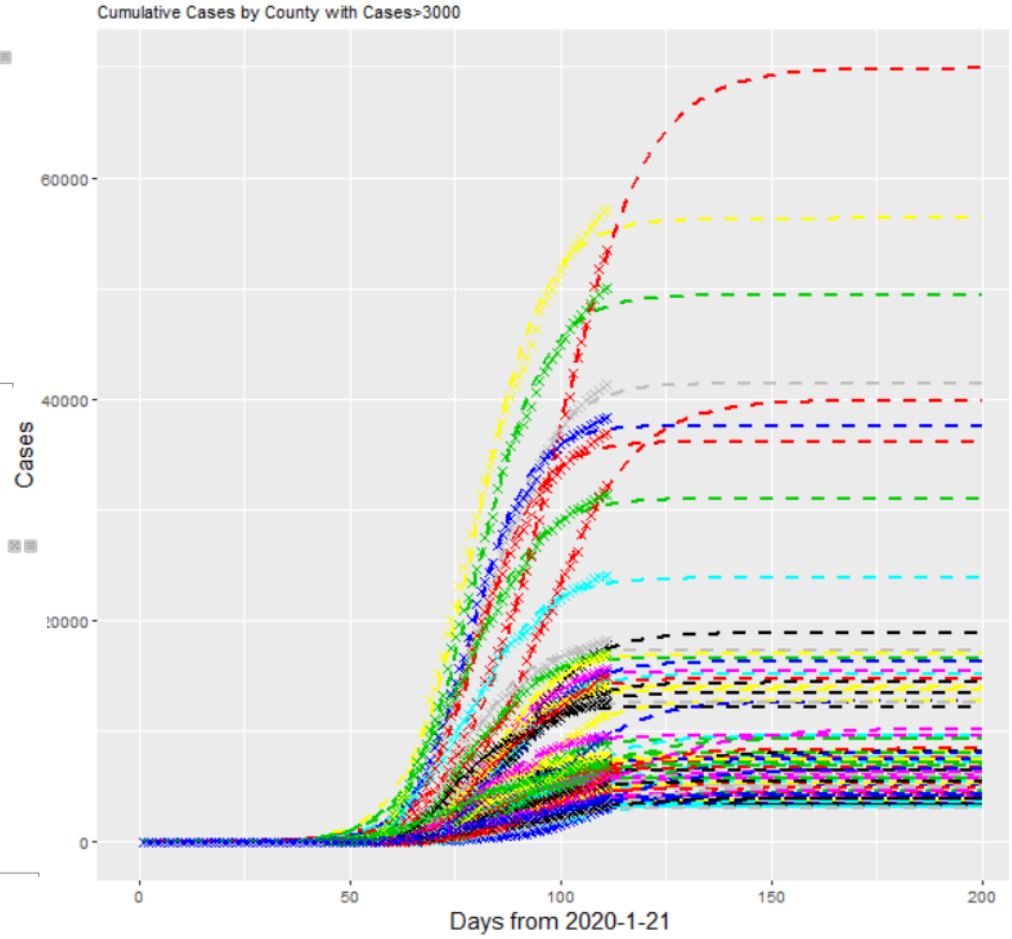
RESULTS LOGISTIC GROWTH MODEL



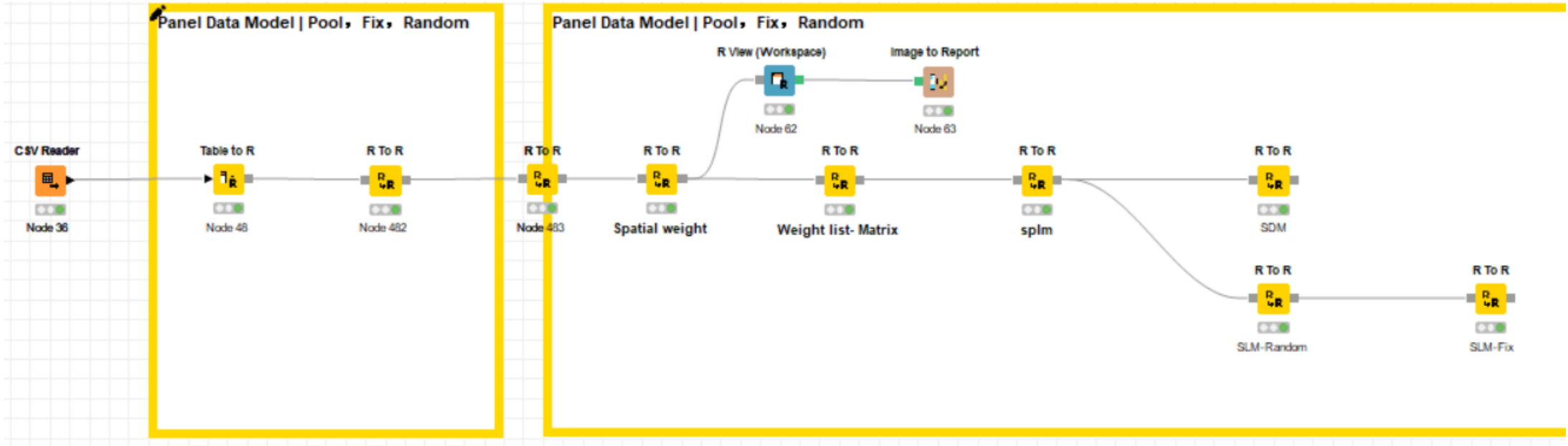








RESULTS SIR INTEGRATED WITH SPATIAL PANEL MODEL



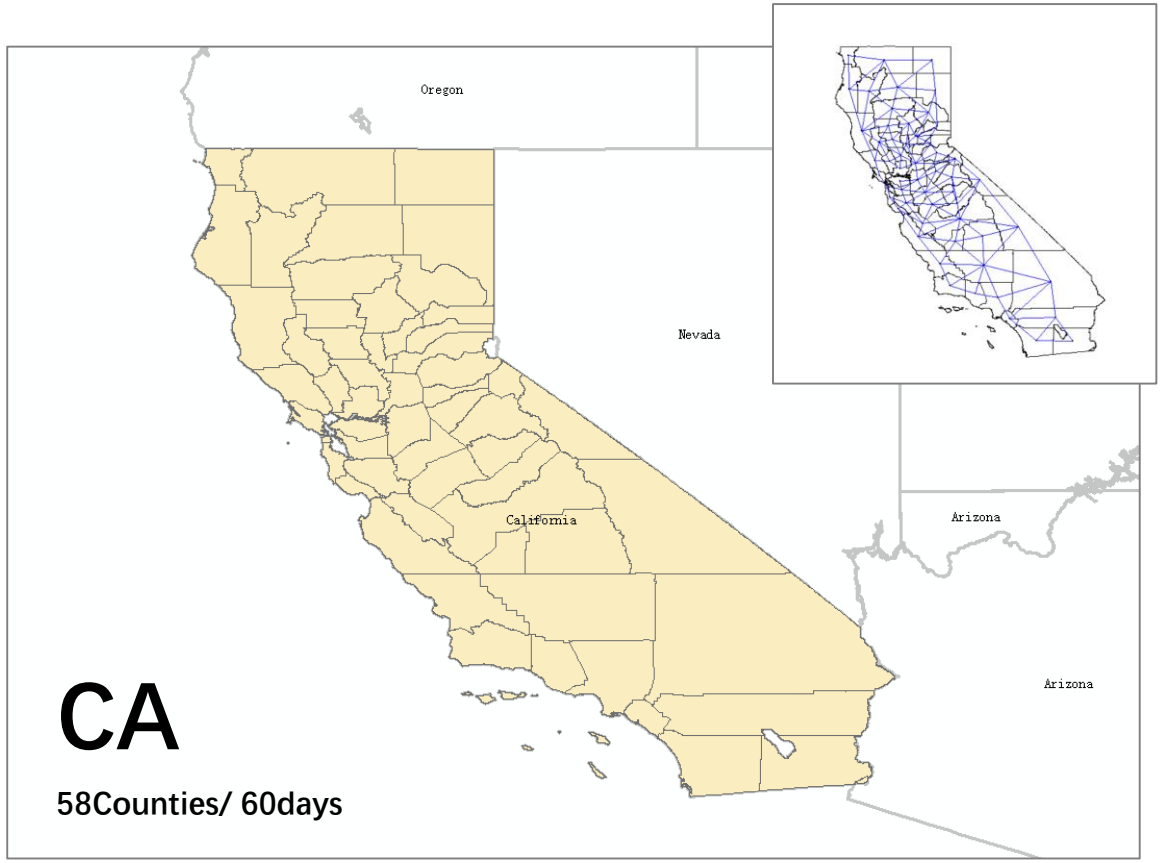
R Script

```r
# call more functions
df2<-df[df$ds!=0,]
df2<-df2[df2$SIN!=0,]
f2<-log(ds)~log(SIN)+t


pool3 = plm(f2, data=df2, model="pooling")
summary(pool3)
```

R Script

```r
#使用poly2nb方法，定义空间关系，现在共点共边（queen =T）
w_cn <- poly2nb(mdata, queen=T)
#计算出来的nb对象，还仅仅是一个临近要素列表，还并非空间权重矩阵，所
w_cn_mat<- nb2listw(w_cn, style="W", zero.policy=TRUE)
```

RESULTS SIR INTEGRATED WITH SPATIAL PANEL MODEL



PANEL DATA MODEL

dI ~ SI/N+t+N

Oneway (individual) effect Random Effect Model
(Swamy-Arora's transformation)

Call:
plm(formula = f, data = dfr, model = "random")

Balanced Panel: n = 58, T = 60, N = 3480

Coefficients:

	Estimate	Std. Error	z-value	Pr(>|z|)	
(Intercept)	-4.4135e+00	1.5839e+00	-2.7864	0.005329	**
SIN	2.6766e-02	5.2925e-04	50.5738	< 2.2e-16	***
t	-4.4802e-02	4.3677e-02	-1.0258	0.305007	
N	2.1676e-05	7.4493e-07	29.0979	< 2.2e-16	***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Total Sum of Squares: 27738000
Residual Sum of Squares: 6488300
R-Squared: 0.76608
Adj. R-Squared: 0.76588
Chisq: 11384.1 on 3 DF, p-value: < 2.22e-16

log(dI)~log(SIN)+t

Pooling Model

Call:
plm(formula = f2, data = dfr2, model = "pooling")

Unbalanced Panel: n = 53, T = 1-60, N = 1732

Coefficients:

	Estimate	Std. Error	t-value	Pr(>|t|)	
(Intercept)	-0.3995454	0.0570217	-7.0069	3.478e-12	***
log(SIN)	0.7866188	0.0124075	63.3986	< 2.2e-16	***
t	-0.0389873	0.0015528	-25.1081	< 2.2e-16	***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Total Sum of Squares: 4387.7
Residual Sum of Squares: 1282.8
R-Squared: 0.70764
Adj. R-Squared: 0.7073
F-statistic: 2092.42 on 2 and 1729 DF, p-value: < 2.22e-16

RESULTS SIR INTEGRATED WITH SPATIAL PANEL MODEL

$$y = \rho \Sigma y + \theta Wx + \alpha X + \varepsilon \qquad \varepsilon = \lambda Wx + \mu$$

SPATIAL PANEL MODEL

Spatial panel fixed effects GM model

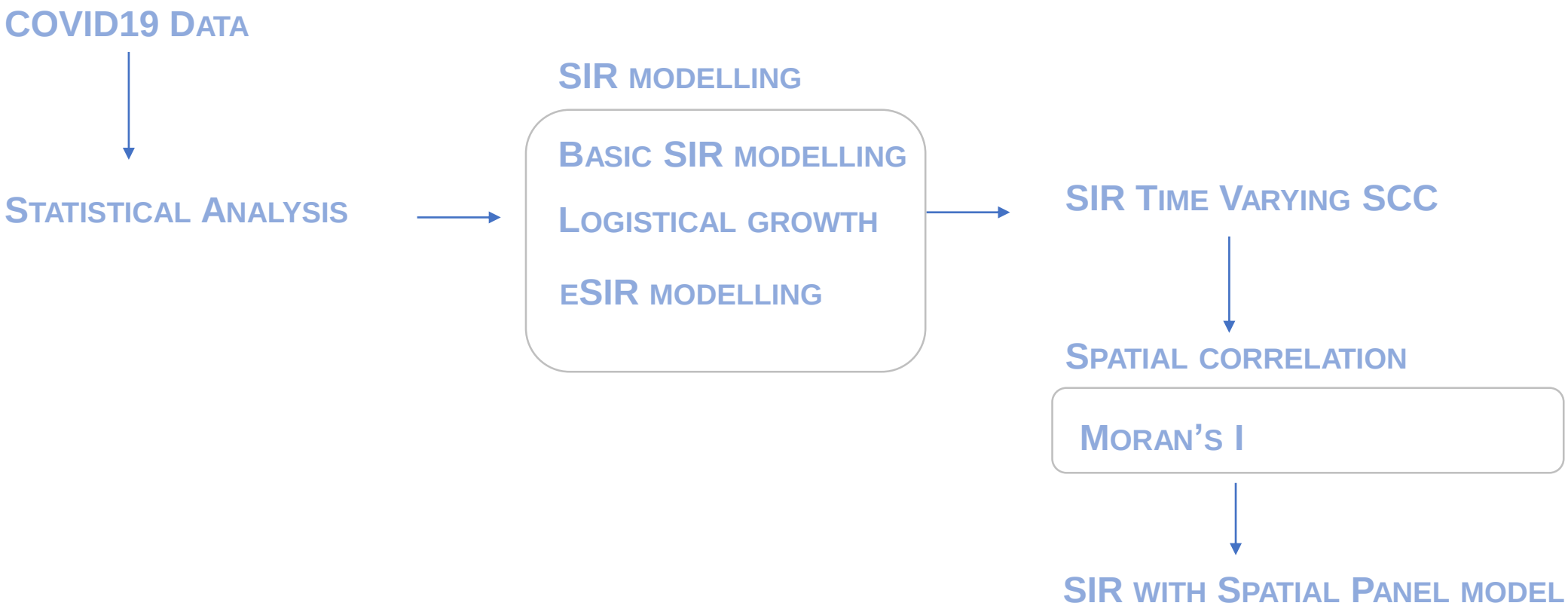
```
Call:
spgm(formula = f, data = dfr, listw = mat2listw(cw), spatial.error = TRUE,
    moments = "fullweights")

Residuals:
      Min.    1st Qu.     Median    3rd Qu.       Max.
-555.45933   -1.77061   -0.10872    0.60889  903.34542

Estimated spatial coefficient, variance components and theta:
            Estimate
rho        8.3095e-02
sigma^2_v 1.7724e+03

Coefficients:
       Estimate  Std. Error t-value Pr(>|t|)
SIN  0.02479794  0.00053399 46.4387   <2e-16 ***
t   -0.00252312  0.04582534 -0.0551   0.9561
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

SDM

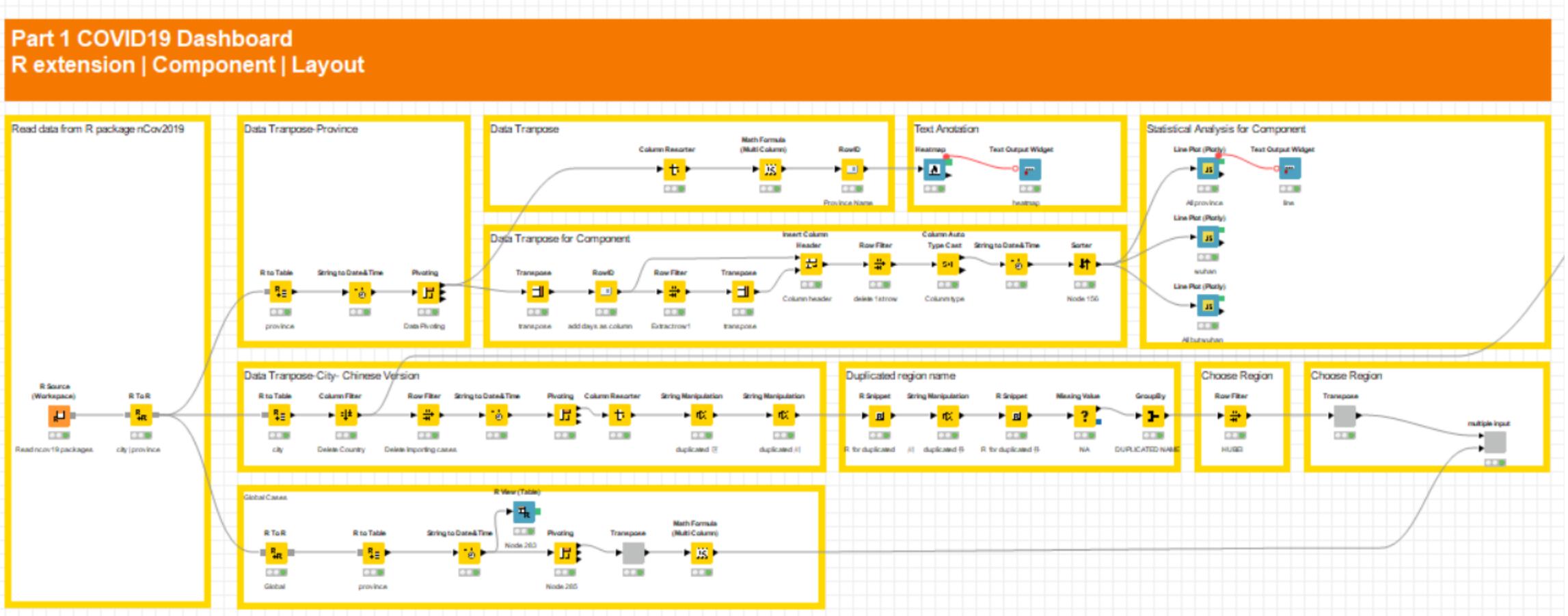
ML panel with spatial lag, AR(1) serial correlation

```
Call:
spreml(formula = f, data = dfr, w = cw, lag = TRUE, errors = "sr",
    method = "BFGS")

Residuals:
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
-628.57   -6.70   -3.01    1.11    0.81 1033.17

Error variance parameters:
    Estimate Std. Error t-value  Pr(>|t|)
psi 0.313712   0.016608  18.889 < 2.2e-16 ***

Spatial autoregressive coefficient:
       Estimate Std. Error t-value Pr(>|t|)
lambda 0.050831   0.017212  2.9533 0.003144 **

Coefficients:
             Estimate  Std. Error t-value  Pr(>|t|)
(Intercept)  9.36792058  1.89050213  4.9553 7.224e-07 ***
SIN          0.03573586  0.00051619 69.2301 < 2.2e-16 ***
t           -0.20519461  0.05150145 -3.9842 6.769e-05 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Flowchart for Data Analysis

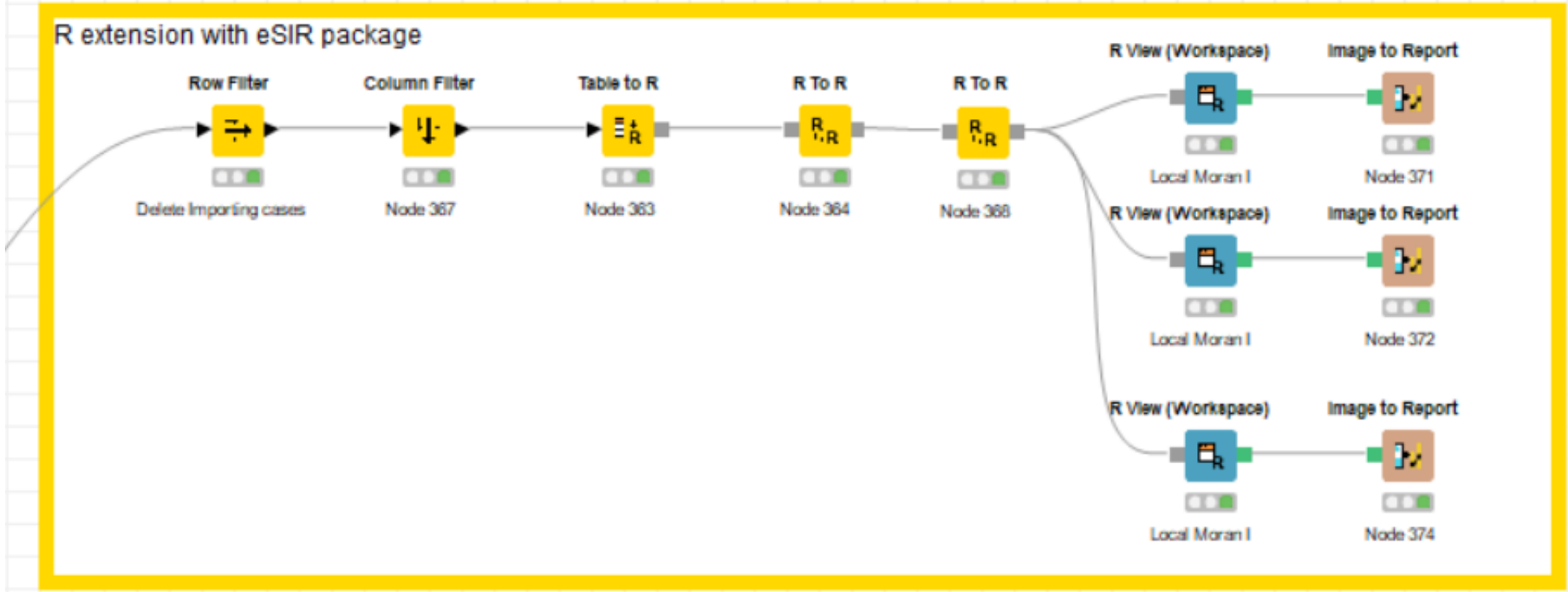


WORKFLOW FOR DATA ANALYSIS

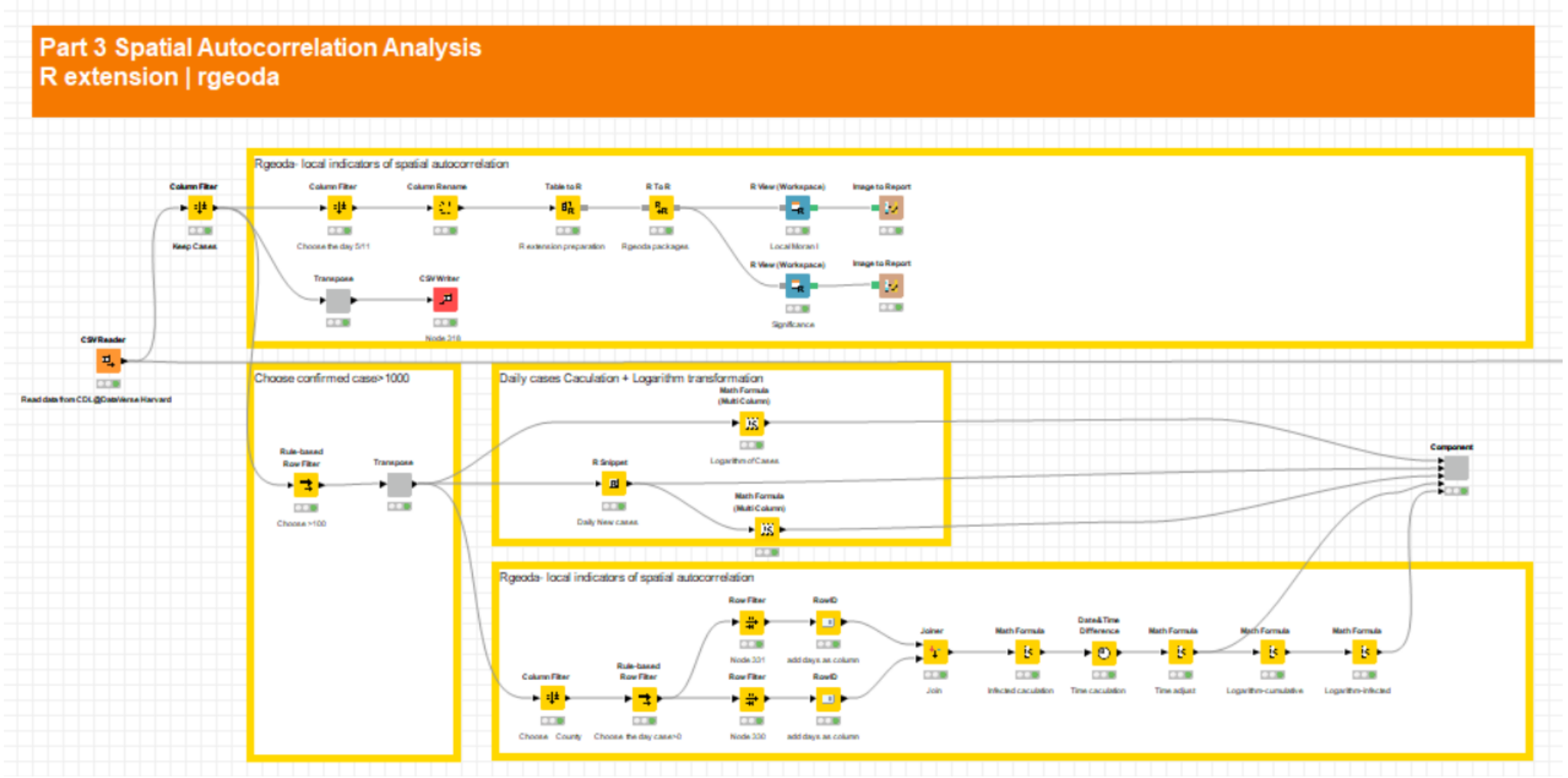


WORKFLOW FOR DATA ANALYSIS

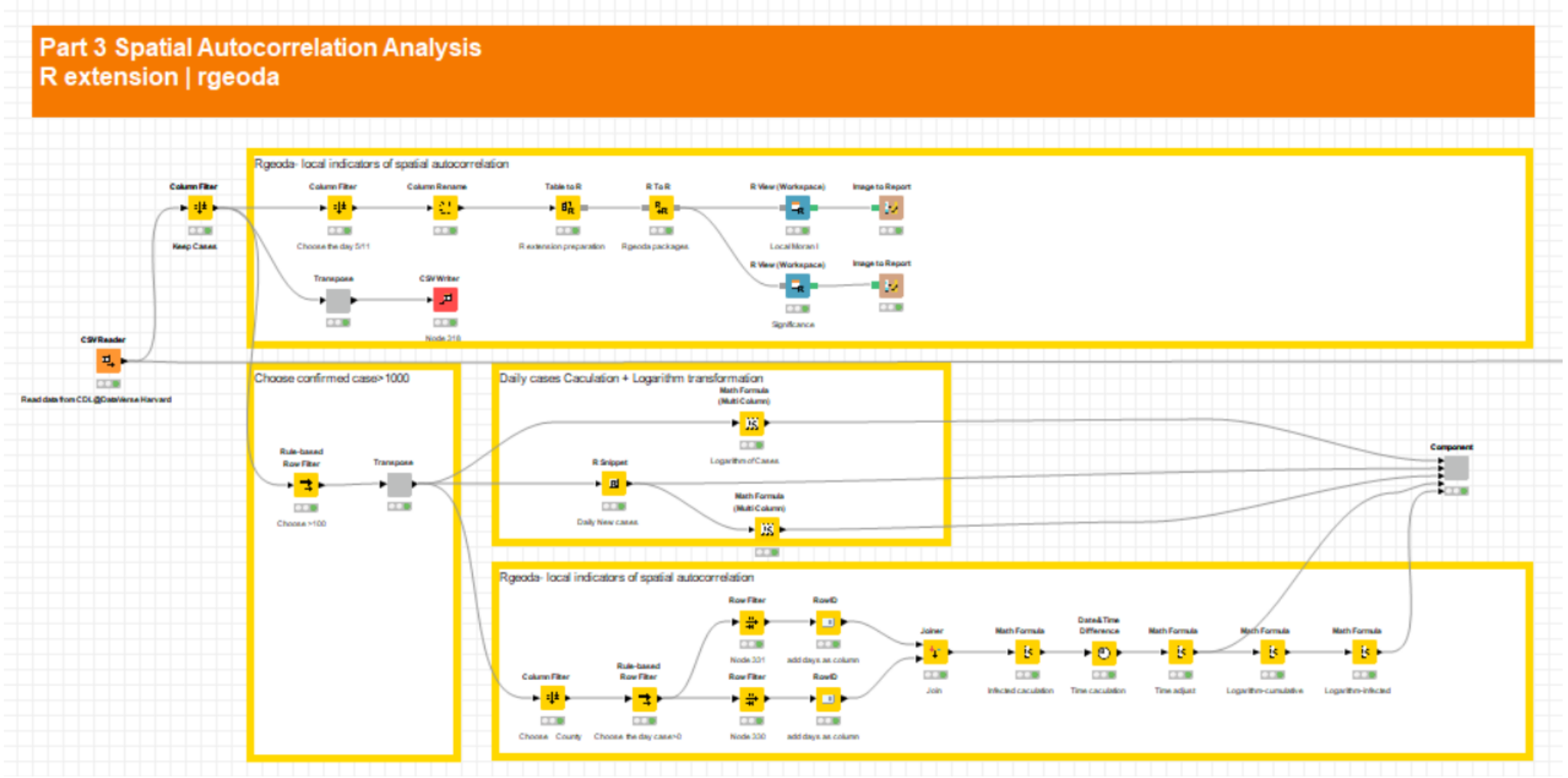
Part 2 COVID19 SIR model
eSIR package



WORKFLOW FOR DATA ANALYSIS

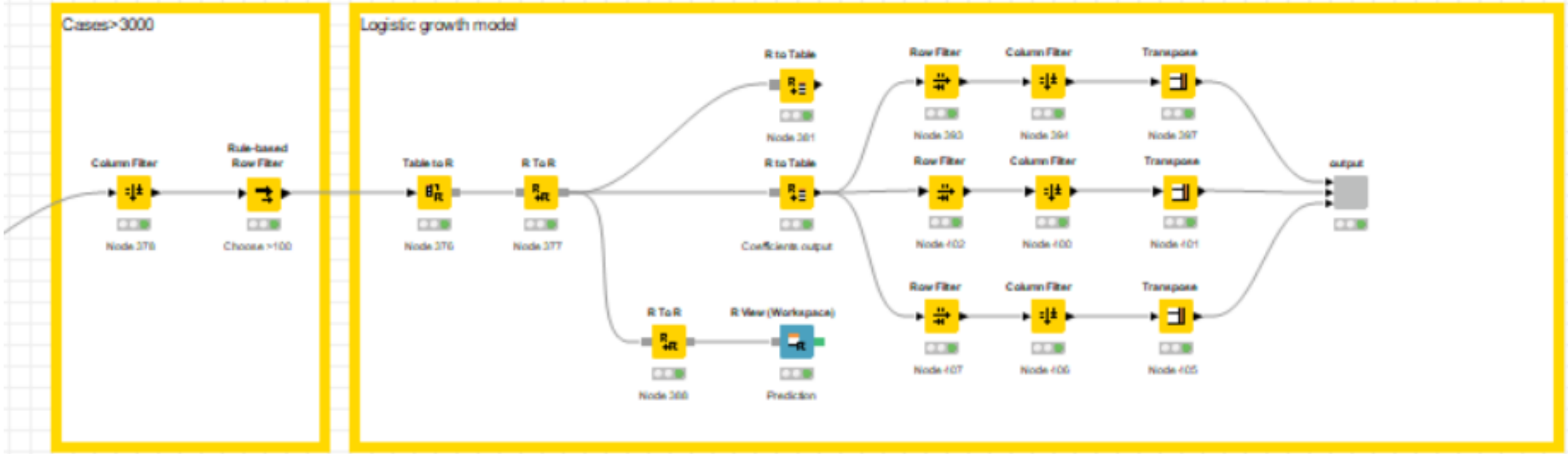


WORKFLOW FOR DATA ANALYSIS



WORKFLOW FOR DATA ANALYSIS

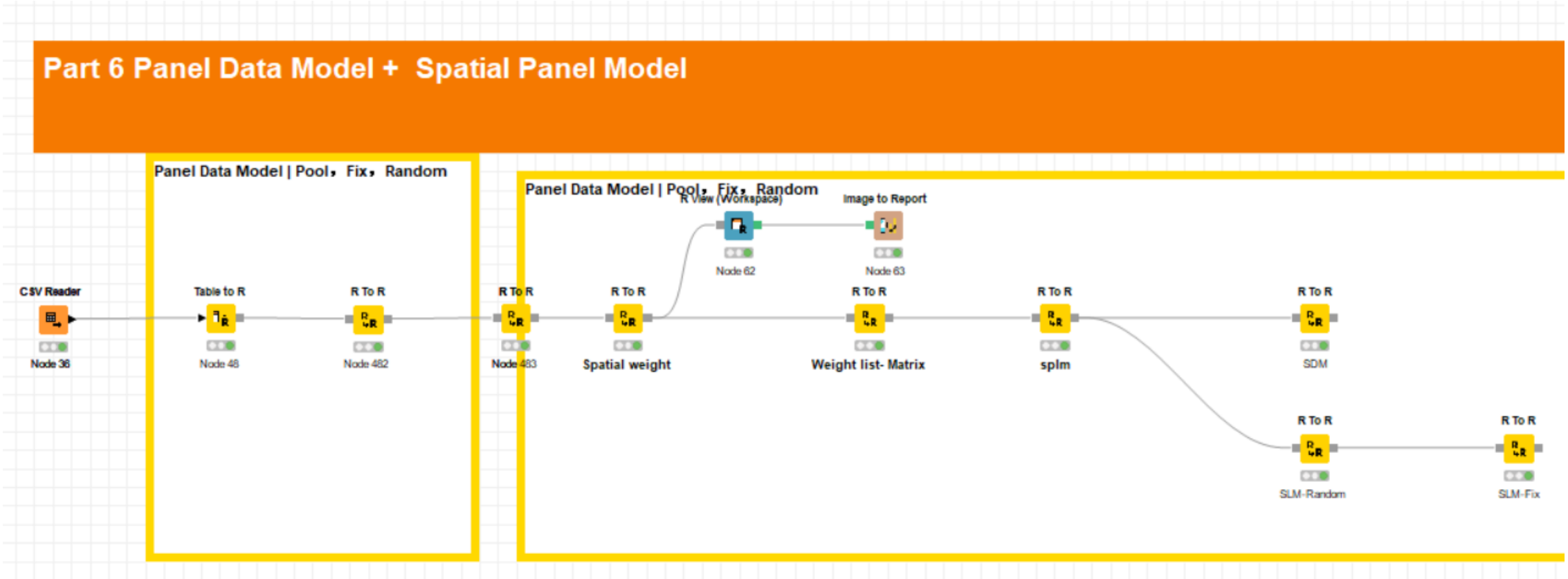
Part 4 COVID19 Simple SIR model
Logistic growth model+ SIR model



WORKFLOW FOR DATA ANALYSIS

WORKFLOW FOR DATA ANALYSIS

WORKFLOW FOR DATA ANALYSIS



Summary and Discussions

Spatial effect detected

The equation of Time varying transmission rate

Beta= $beta_0$^t

Spatial SIR need more investigation

More workflow could be developed