

Historical Data on Relevant Risks

June

- Relevant Risk filtering and identification

July

- Historical Cold Snap data
- Historical Pipeline Disruption frequency data

August

- Historical Pipeline Disruption impact data
- Historical Wind and Solar Intermittency
- Historical Relevant Risk data

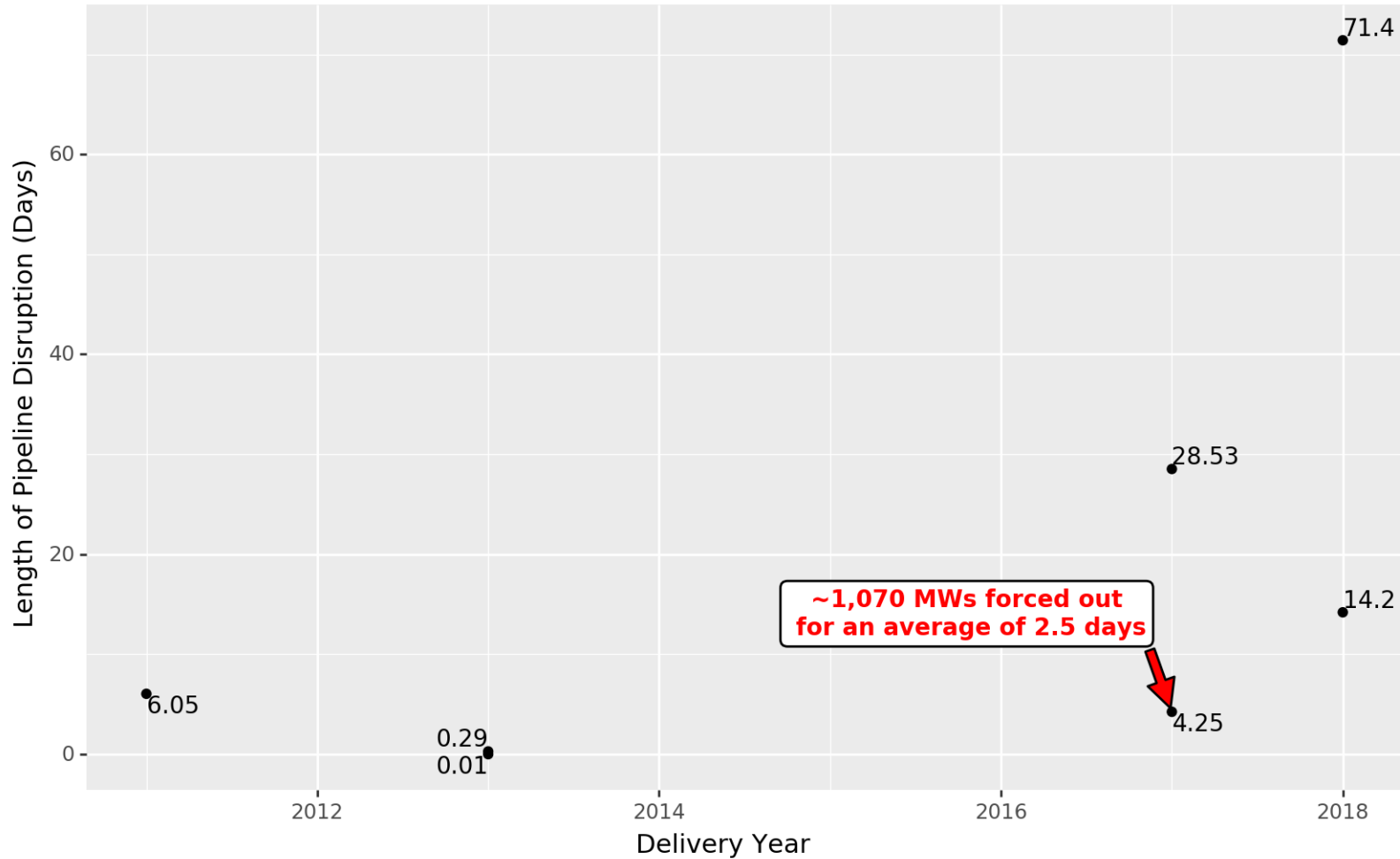
Relevant Risks	
Long Duration Cold Snap	Covered in July
Short Duration Cold Snap	
Natural Gas Pipeline Disruptions	Covered in July and to be continued today
Solar Intermittency	
Wind Intermittency	To be covered today
Coal Refueling (Bridge Failure)	
Coal Refueling (Lock and Dam Failure)	To be covered today
Coal Refueling (Rail Failure)	
Coal Refueling (River Freezing)	
Coal Unavailability (Coal Quality)	
Natural Gas Unavailability Non-Firm Units	
Oil Refueling (Oil Terminal)	
Oil Refueling (Truck Restrictions)	
Nuclear Regulatory Shutdown (Fuel Related)	
Nuclear Regulatory Shutdown (Non-Fuel Related)	
Nuclear Unavailability (High Winds)	
Hydro Unavailability (Freezing Rivers)	
River Freezing (Cooling Water Impacts)	
Ice Storm (Transportation Impacts)	

Relevant Risk: Pipeline Disruptions

Based on Pipeline and Hazardous Material Safety Administration (PHMSA) data:

$$\frac{10 \text{ Pipeline Disruptions}}{9 \text{ Winter Periods}} \rightarrow 1.1 \frac{\text{Pipeline Disruptions}}{\text{DY Winter}}$$

Historical Impact of Pipeline Disruptions



~1,070 MWs forced out for an average of 2.5 days

Only the December 2017 disruption impacted PJM generation (approximately 1,070 MW of forced outages)

The rest of the pipeline disruptions that have occurred during Winter in the PJM footprint since 2010 have not impacted PJM generation

Duration shown for 7 events only. Outliers and events with missing data are not shown

- It is difficult to establish the impact of a pipeline disruption on PJM generation based on GADS data because there are no specific cause codes referencing pipeline disruptions
- The limited impact that PJM generation has experienced due to recent pipeline disruptions is not necessarily an indicator of future impact levels
- Had some of the past disruptions occurred at different geographic locations or other times of the year under more stressful conditions, the impact on PJM generation could have been more significant

Relevant Risk: Wind and Solar Intermittency

Cold Snaps Analyzed:

Cold Snap	Start	Stop	Duration
1	Jan. 21, 2014	Jan. 30 2014	10 Days
2	Jan. 6, 2015	Jan. 10, 2015	5 Days
3	Feb. 13, 2015	Feb. 20, 2015	8 Days
4	Dec. 26, 2017	Jan. 7, 2018	13 Days

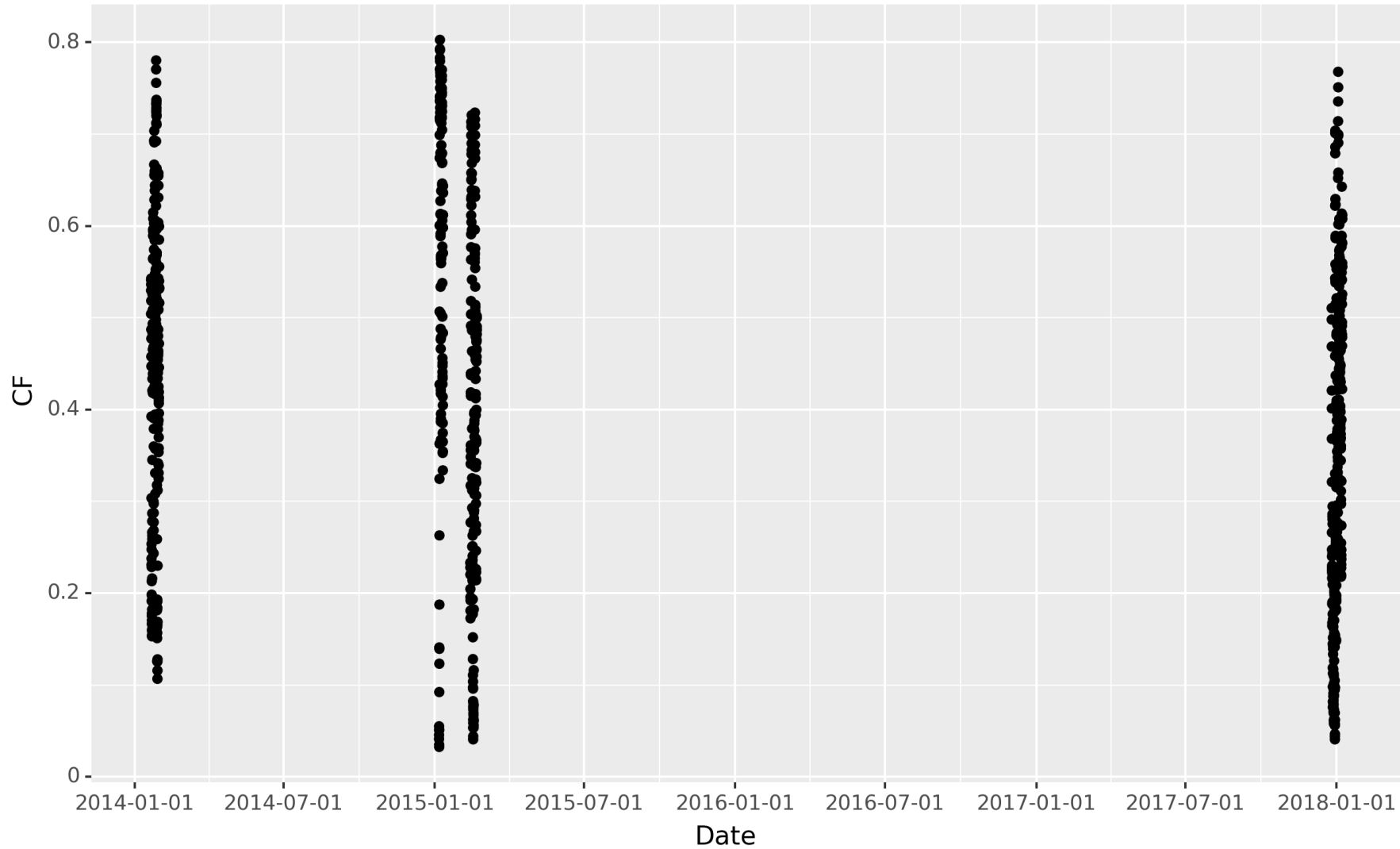
Capacity Factor:

$$CF = \frac{\text{Actual Hourly Output}}{\text{Total Installed Nameplate}}$$

For solar and wind resources, capacity factor serves as an indicator of how effectively the resources are performing

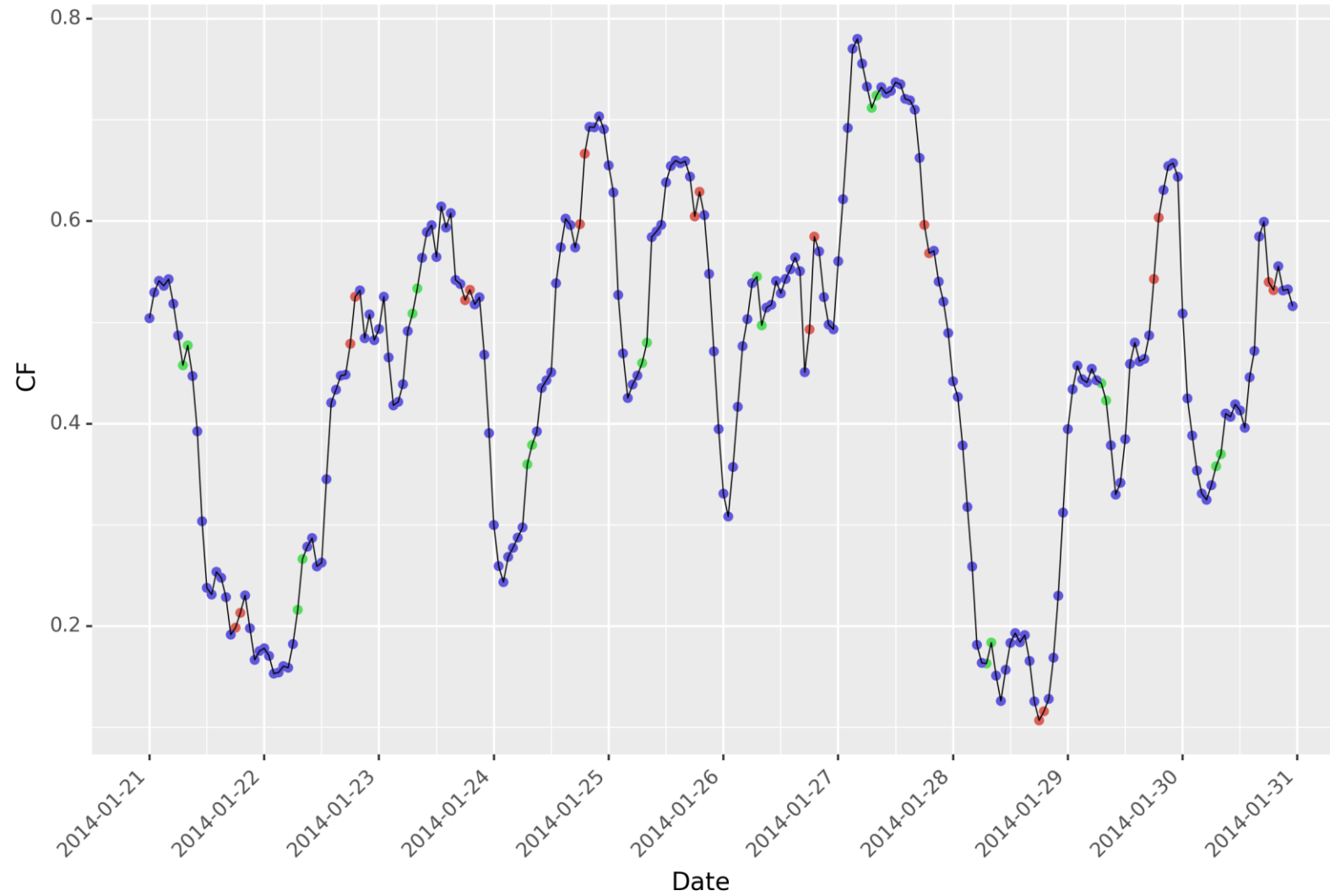
Winter Peak Hours:

AM Peak	PM Peak
HE08 & HE09	HE19 & HE20



- Wide CF distribution
- All CFs > 0.00
- Many hours are much higher than the anticipated 0.13 CF

Wind Hourly Capacity Factor (01/21/14 – 01/30/14)

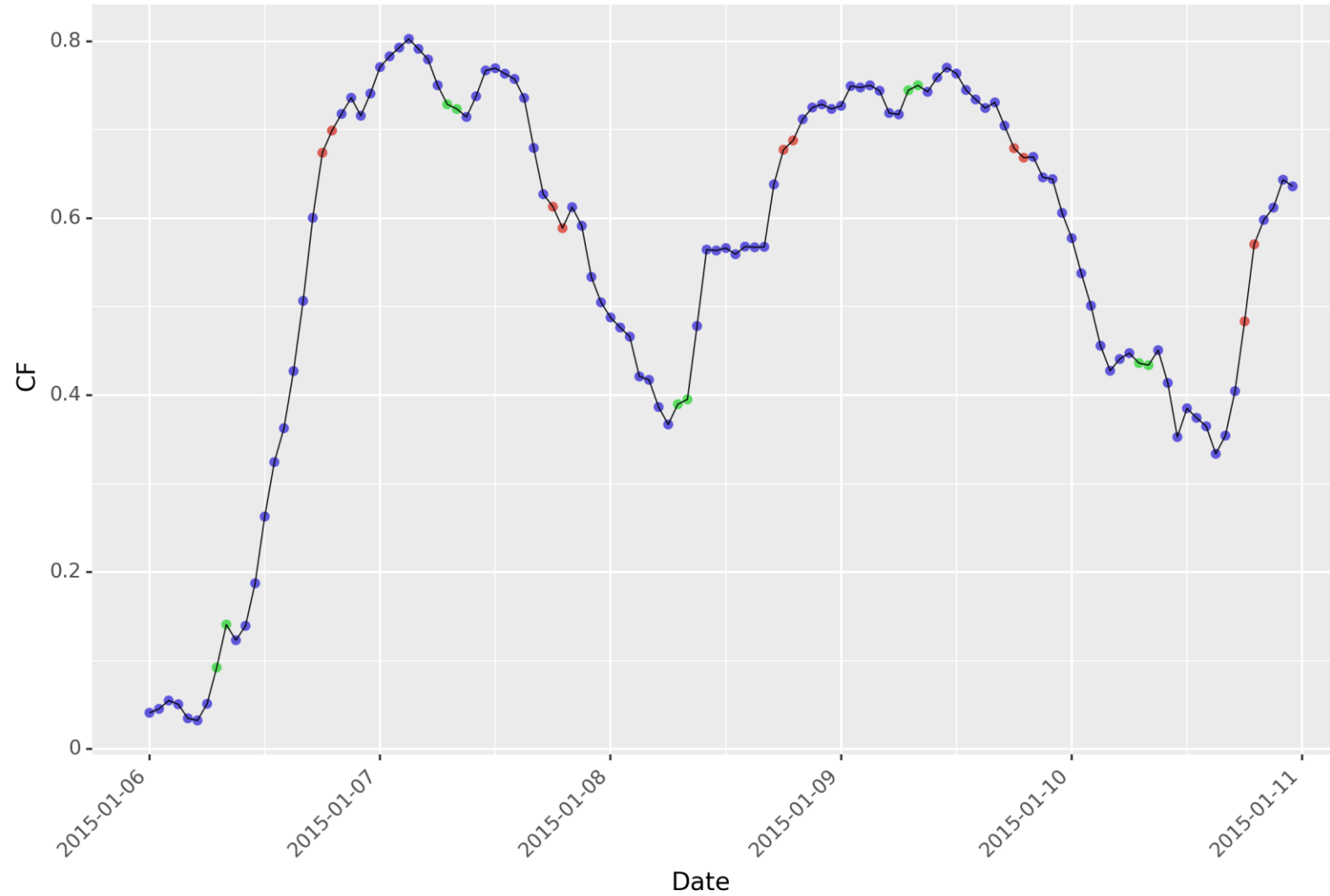


HourType

- EveningPeakHours
- MorningPeakHours
- OtherHours

Morning Hours	Evening Hours
Min: 0.16	Min: 0.11
Mean: 0.43	Mean: 0.48
Max: 0.72	Max: 0.67

Wind Hourly Capacity Factor (01/06/15 – 01/10/15)

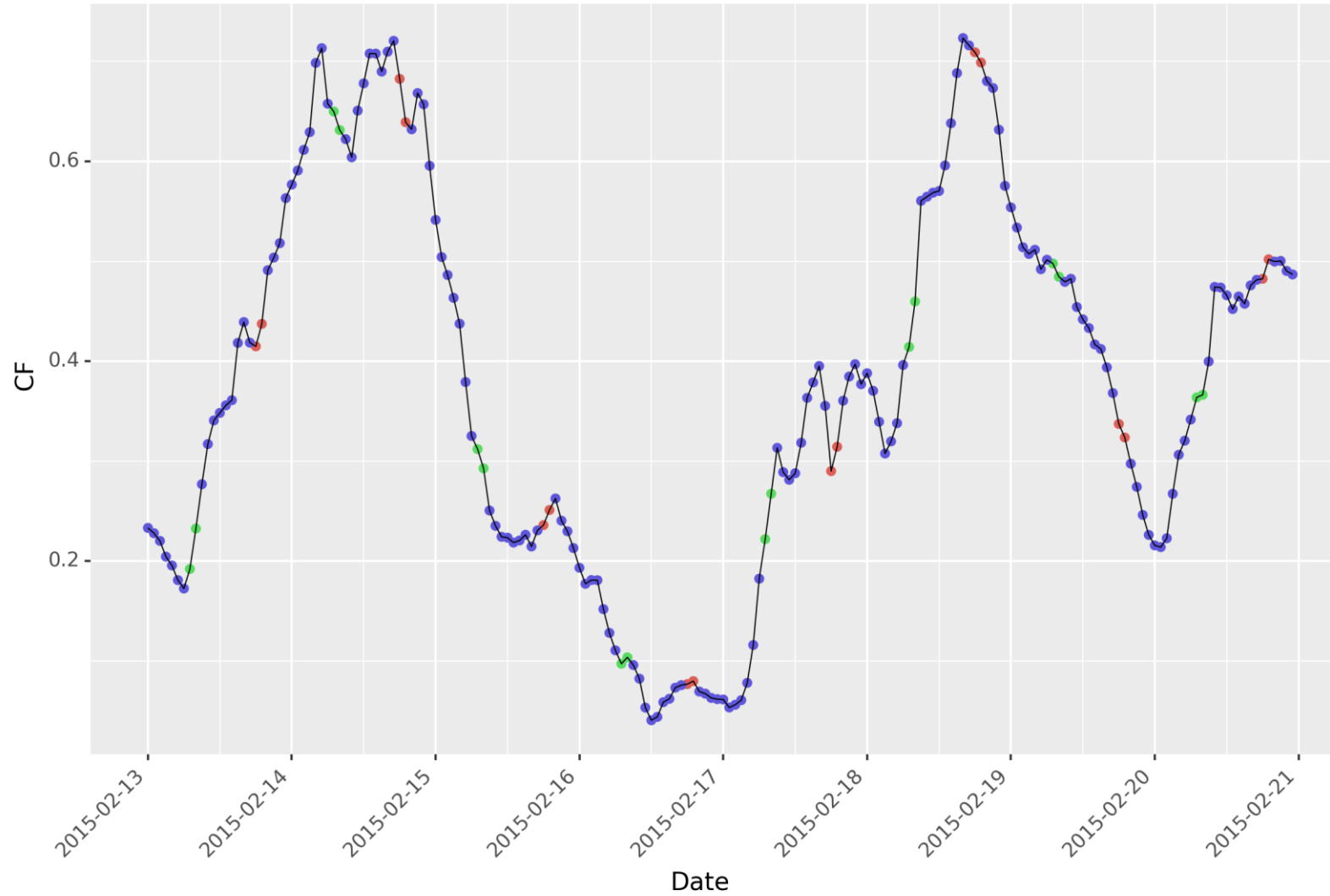


HourType

- EveningPeakHours
- MorningPeakHours
- OtherHours

Morning Hours	Evening Hours
Min: 0.09	Min: 0.48
Mean: 0.48	Mean: 0.63
Max: 0.75	Max: 0.70

Wind Hourly Capacity Factor (02/13/15 – 02/20/15)

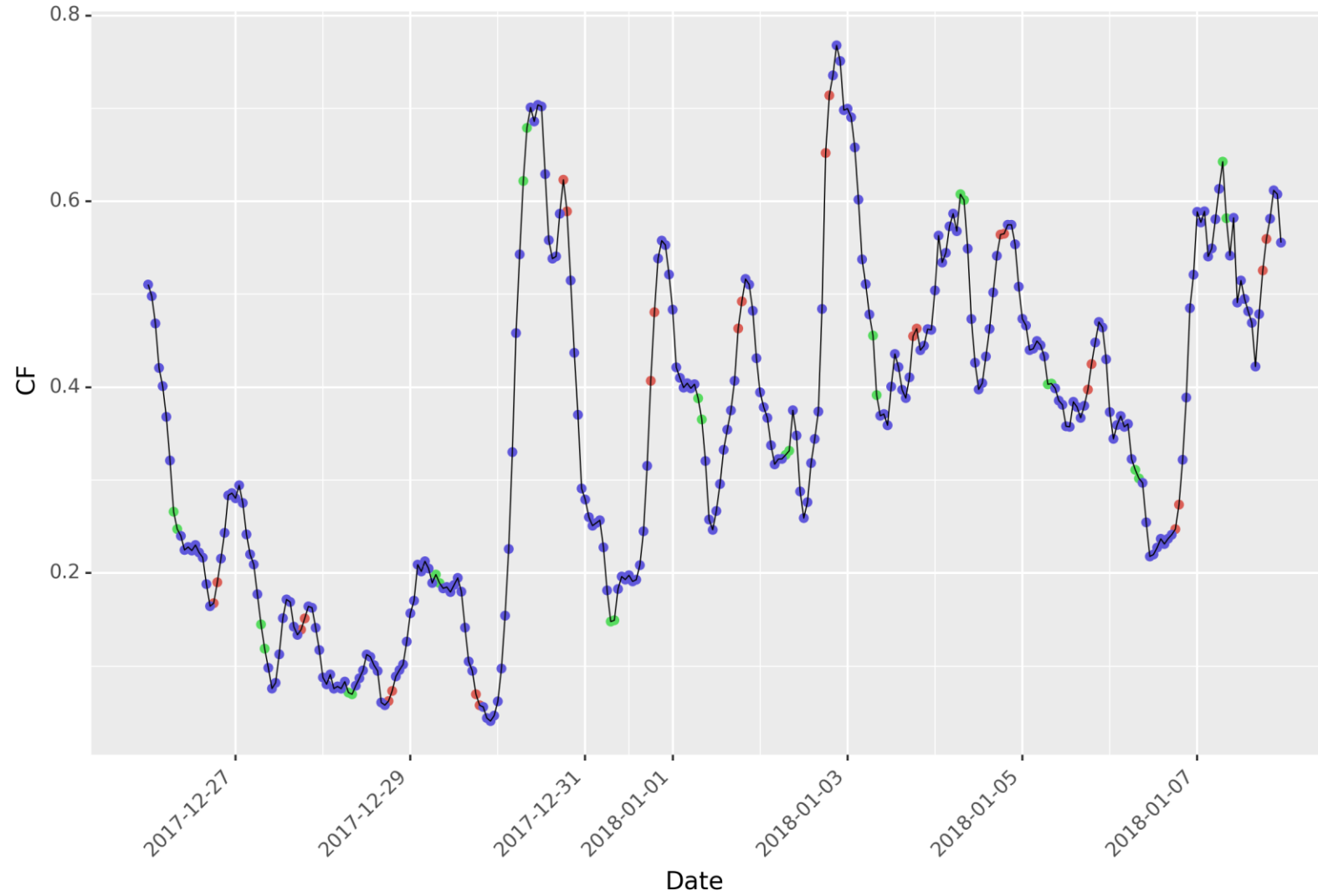


HourType

- EveningPeakHours
- MorningPeakHours
- OtherHours

Morning Hours	Evening Hours
Min: 0.10	Min: 0.08
Mean: 0.35	Mean: 0.40
Max: 0.65	Max: 0.71

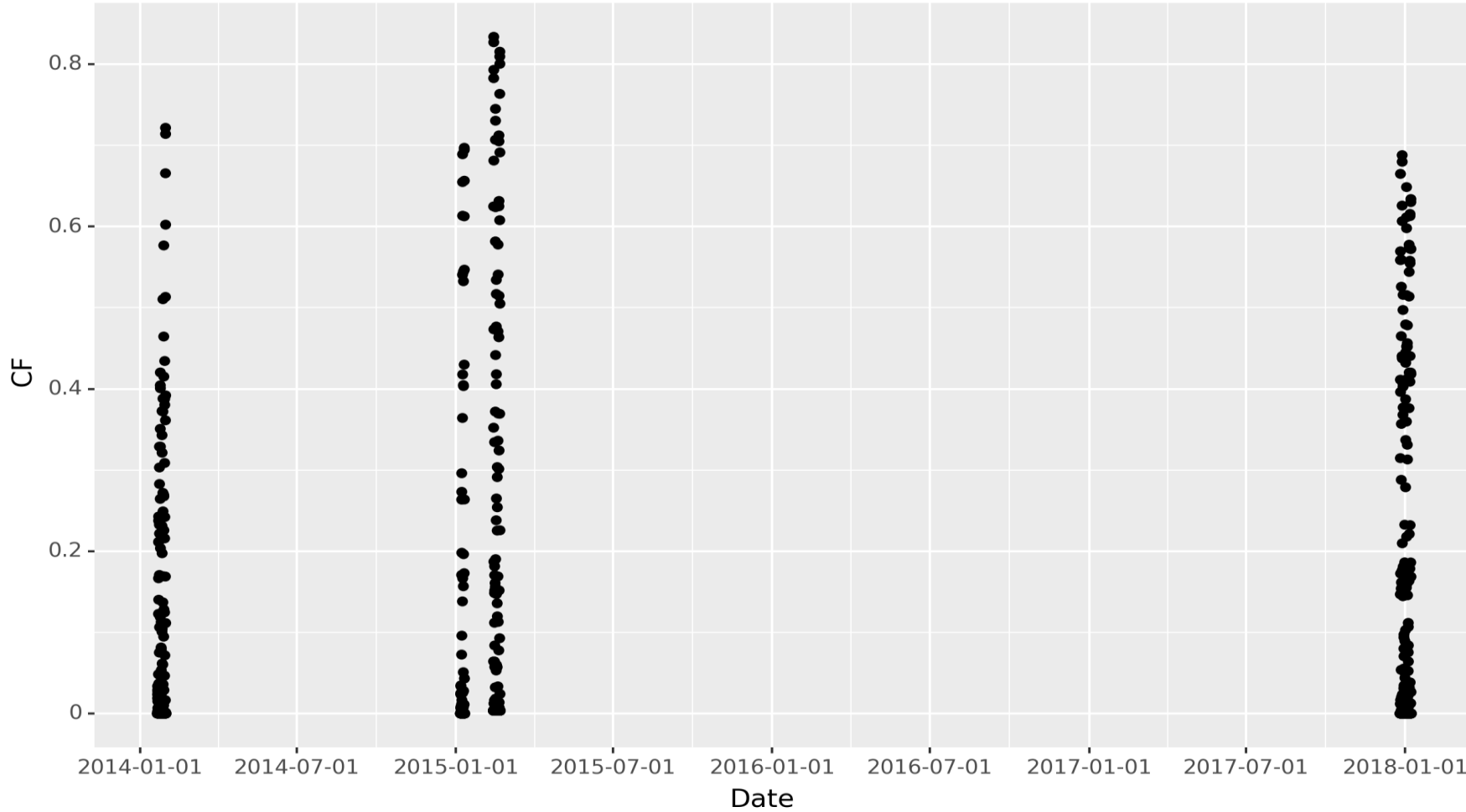
Wind Hourly Capacity Factor (12/26/17 – 01/07/18)



HourType

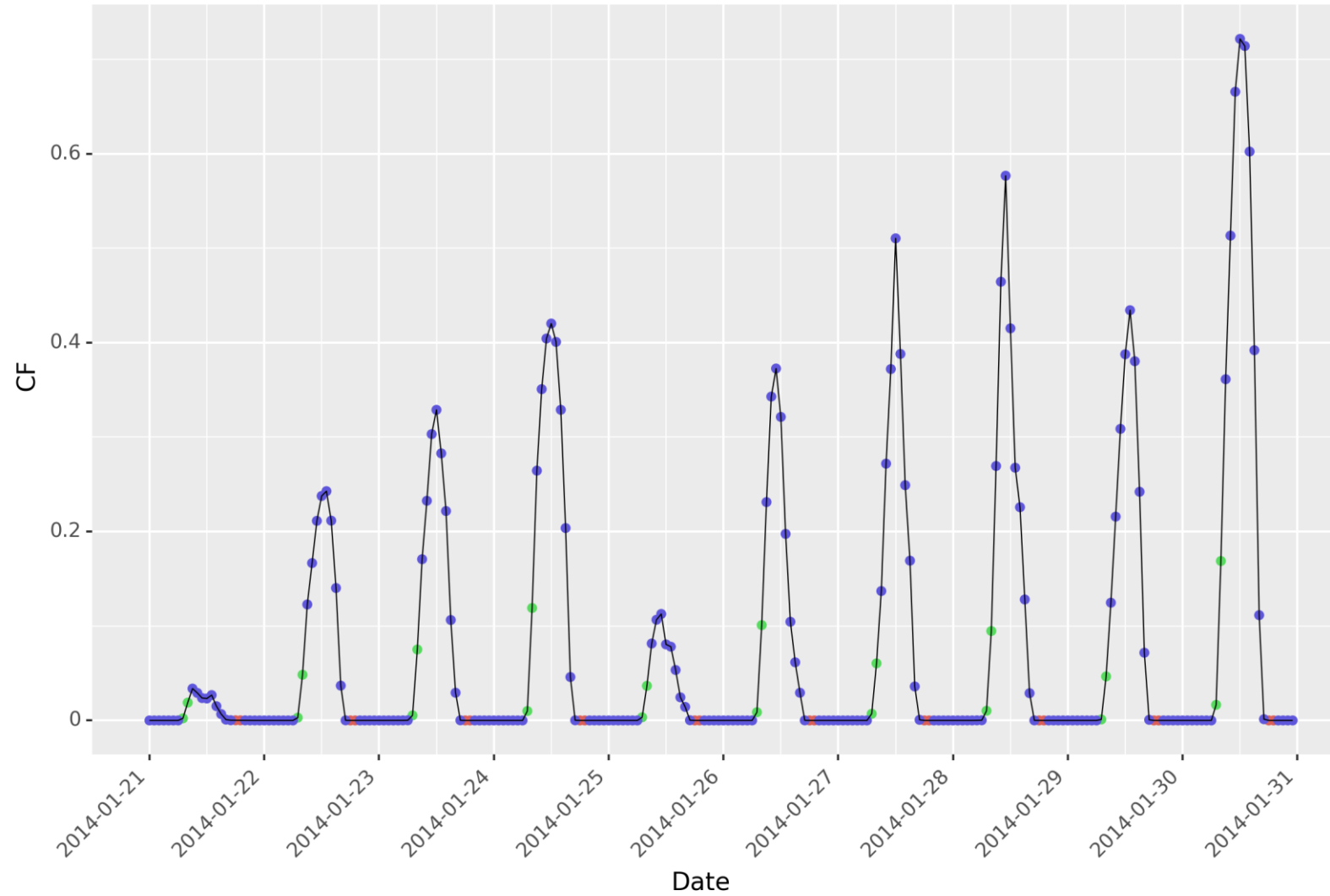
- EveningPeakHours
- MorningPeakHours
- OtherHours

Morning Hours	Evening Hours
Min: 0.07	Min: 0.06
Mean: 0.35	Mean: 0.38
Max: 0.68	Max: 0.71



- Wide CF distribution
- Many CFs = 0.00
- Overall average is lower than the anticipated 0.38 CF

Solar Hourly Capacity (01/21/14 – 01/30/14)

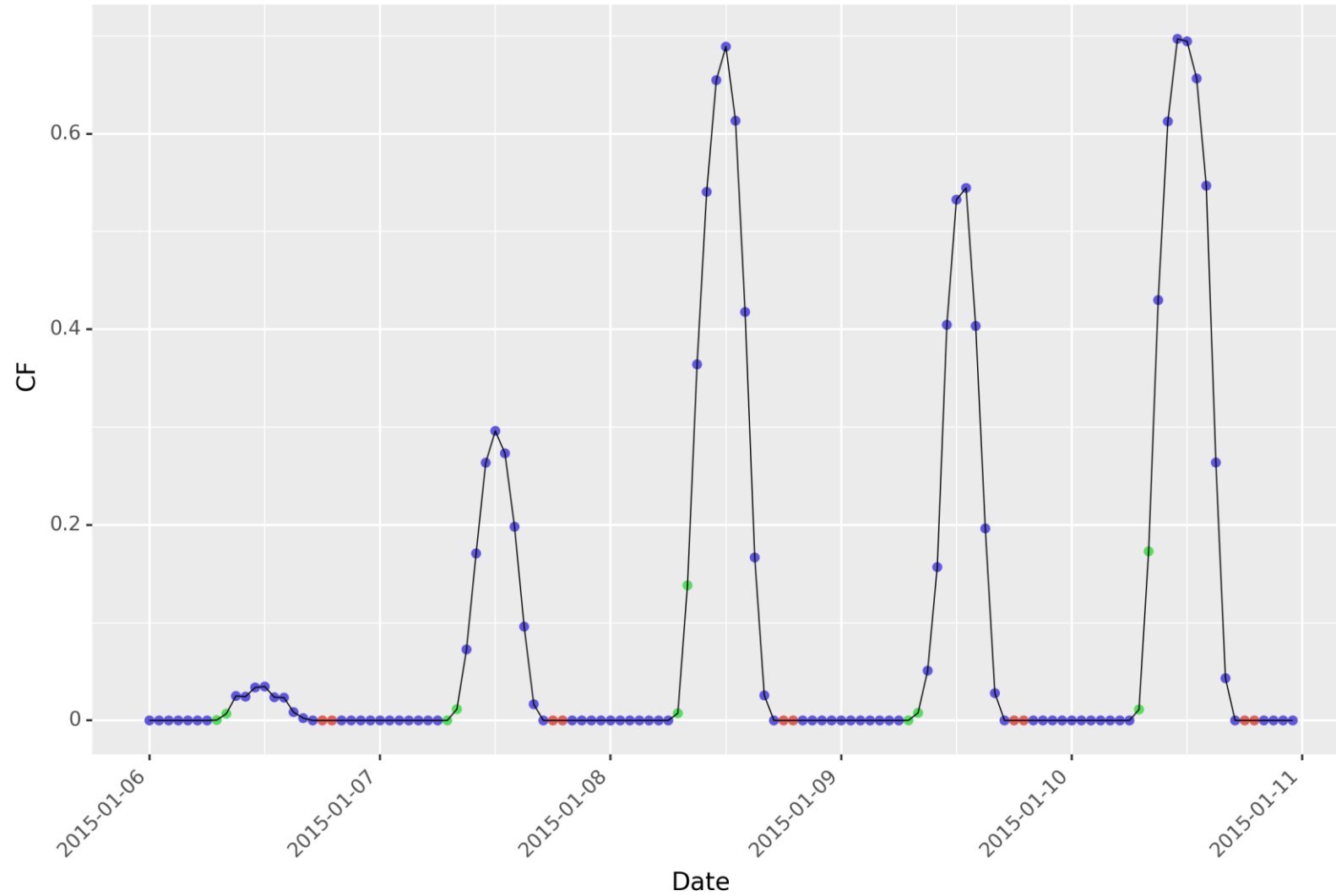


HourType

- EveningPeakHours
- MorningPeakHours
- OtherHours

Morning Hours	Evening Hours
Min: 0.001	Min: 0.000
Mean: 0.042	Mean: 0.000
Max: 0.169	Max: 0.000

Solar Hourly Capacity Factor (01/06/15 – 01/10/15)

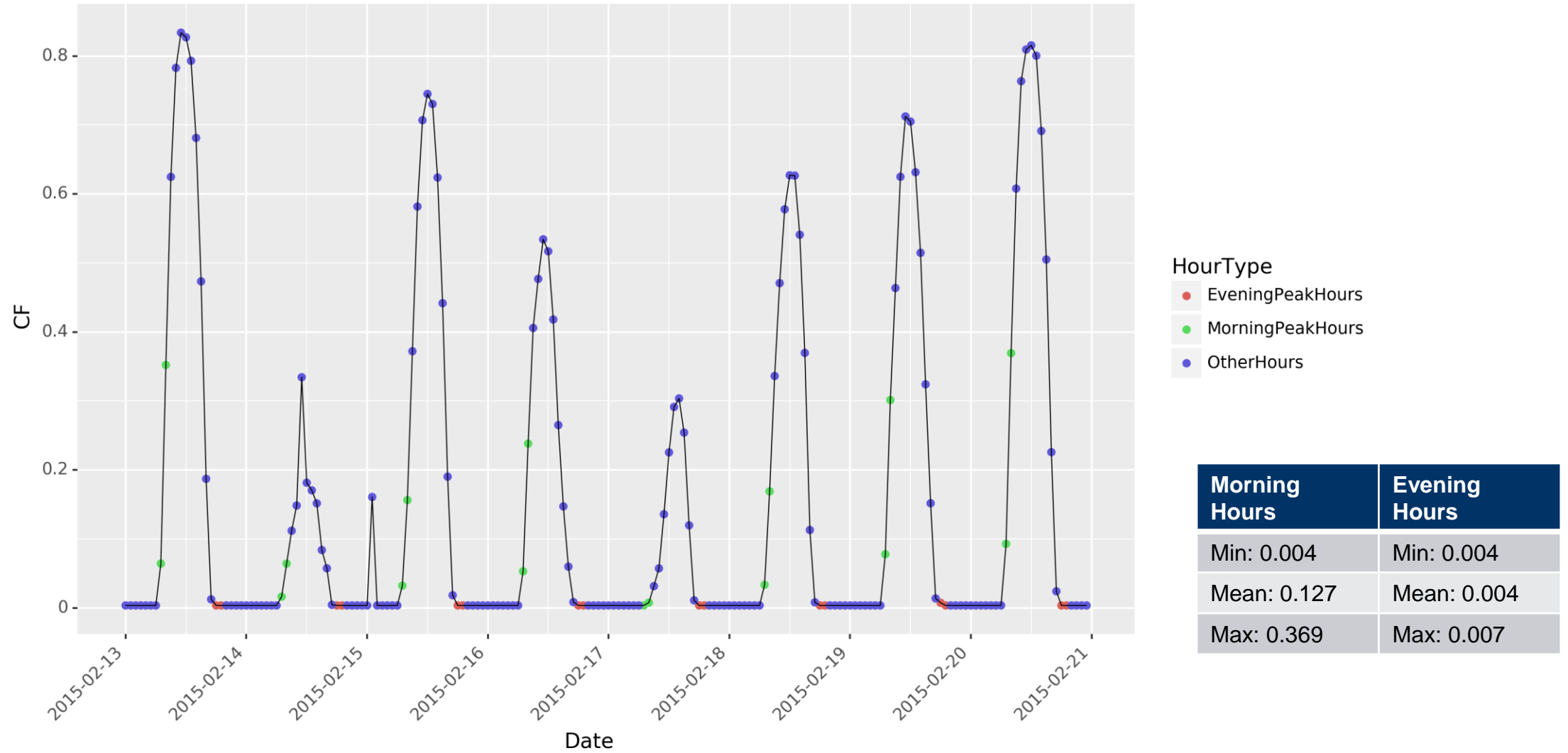


HourType

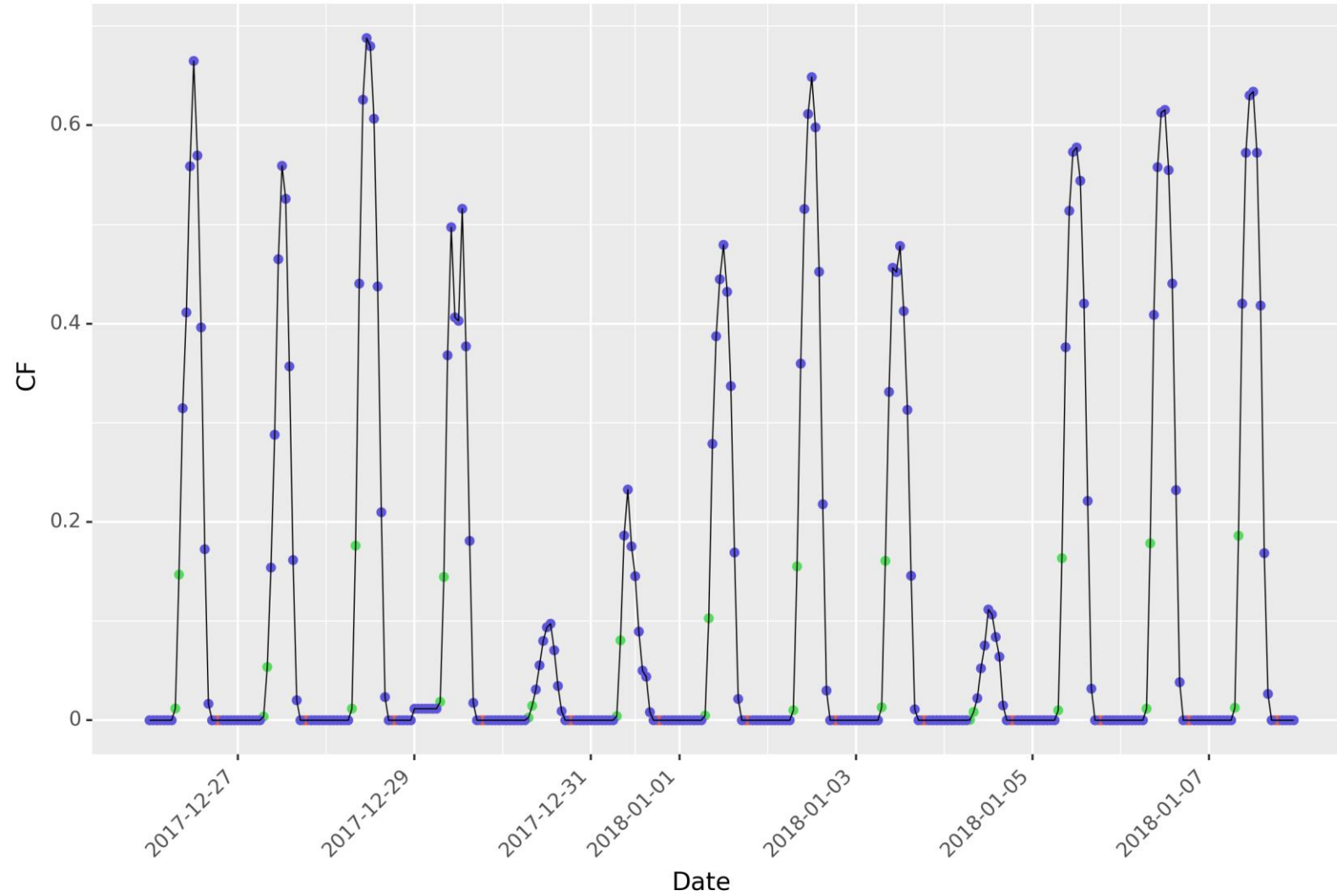
- EveningPeakHours
- MorningPeakHours
- OtherHours

Morning Hours	Evening Hours
Min: 0.000	Min: 0.000
Mean: 0.036	Mean: 0.000
Max: 0.173	Max: 0.000

Solar Hourly Capacity Factor (02/13/15 – 02/20/15)



Solar Hourly Capacity Factor (12/26/17 – 01/07/18)



HourType

- EveningPeakHours
- MorningPeakHours
- OtherHours

Morning Hours	Evening Hours
Min: 0.000	Min: 0.000
Mean: 0.065	Mean: 0.000
Max: 0.186	Max: 0.000

Wind:

- Wide distribution of capacity factors during all four cold snaps
- Capacity factors generally outperform the anticipated capacity factor of 0.13 during both peak and non-peak hours

Solar:

- Wide distribution of capacity factors during all four cold snaps
- Capacity factors never reach the anticipated capacity factor of 0.38 during peak hours
- Shorter winter days translate to a small number of daily hours at or above the anticipated capacity factor of 0.38

Relevant Risk: Fuel Specific Risks

- NERC established data collection system with required data submission for conventional generators 20 MW and greater
- Each event is unique and has an event type that describes the outage/derate and a cause code that describes the mechanism triggering the event

NERC GADS Website:

[https://www.nerc.com/pa/RAPA/gads/Pages/GeneratingAvailabilityDataSystem-\(GADS\).aspx](https://www.nerc.com/pa/RAPA/gads/Pages/GeneratingAvailabilityDataSystem-(GADS).aspx)

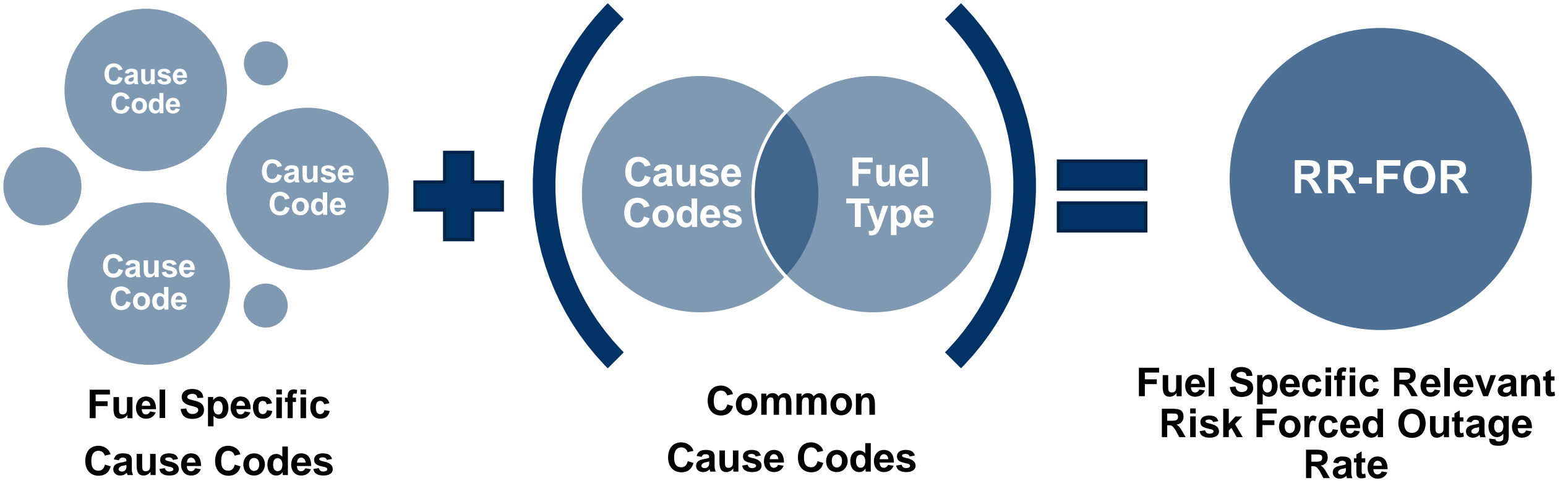
2019 GADS Cause Codes:

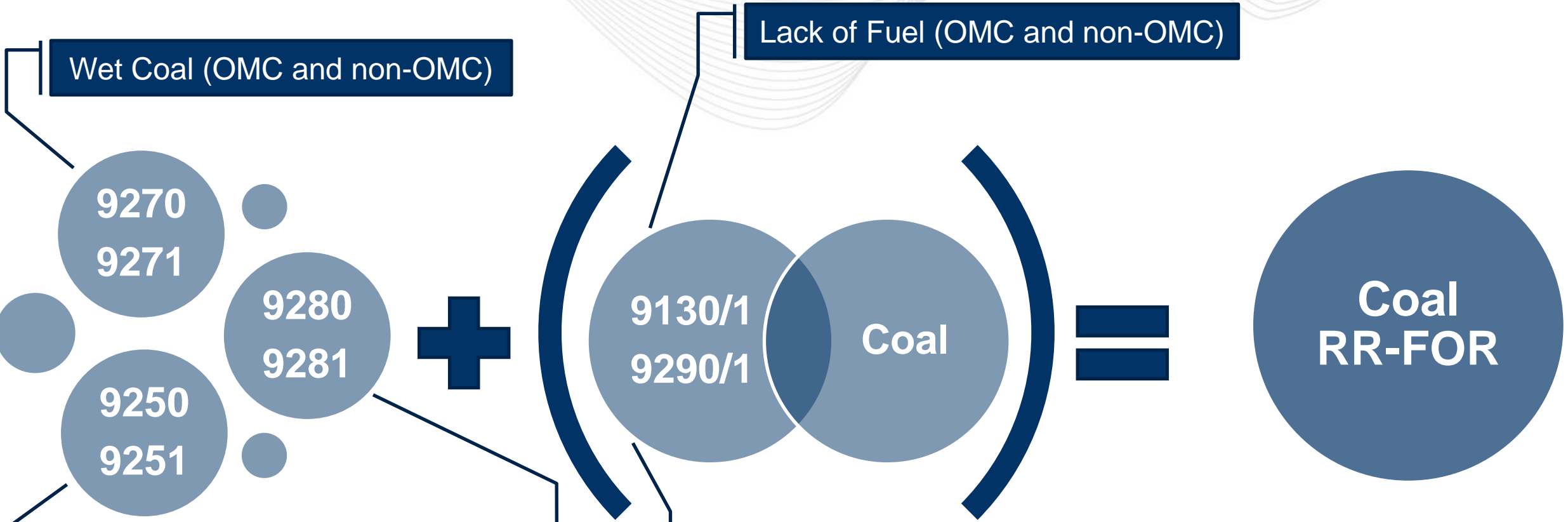
https://www.nerc.com/pa/RAPA/gads/DataReportingInstructions/2019_GADS_Cause_Codes.xlsx

Relevant Risks
Long Duration Cold Snap
Short Duration Cold Snap
Natural Gas Pipeline Disruptions
Solar Intermittency
Wind Intermittency
Coal Refueling (Bridge Failure)
Coal Refueling (Lock and Dam Failure)
Coal Refueling (Rail Failure)
Coal Refueling (River Freezing)
Coal Unavailability (Coal Quality)
Natural Gas Unavailability Non-Firm Units
Oil Refueling (Oil Terminal)
Oil Refueling (Truck Restrictions)
Nuclear Regulatory Shutdown (Fuel Related)
Nuclear Regulatory Shutdown (Non-Fuel Related)
Nuclear Unavailability (High Winds)
Hydro Unavailability (Freezing Rivers)
River Freezing (Cooling Water Impacts)
Ice Storm (Transportation Impacts)



Fuel Specific Relevant Risk Forced Outage Rate (RR-FOR)





Wet Coal (OMC and non-OMC)

Lack of Fuel (OMC and non-OMC)

Frozen Coal (OMC and non-OMC)

Other Fuel Quality Problems (OMC and non-OMC)

Low BTU Coal (OMC and non-OMC)

Note: Diagram does not identify all cause codes, see the technical appendix slides for a complete listing

Cold Snaps Analyzed:

Forced Outage Rate:

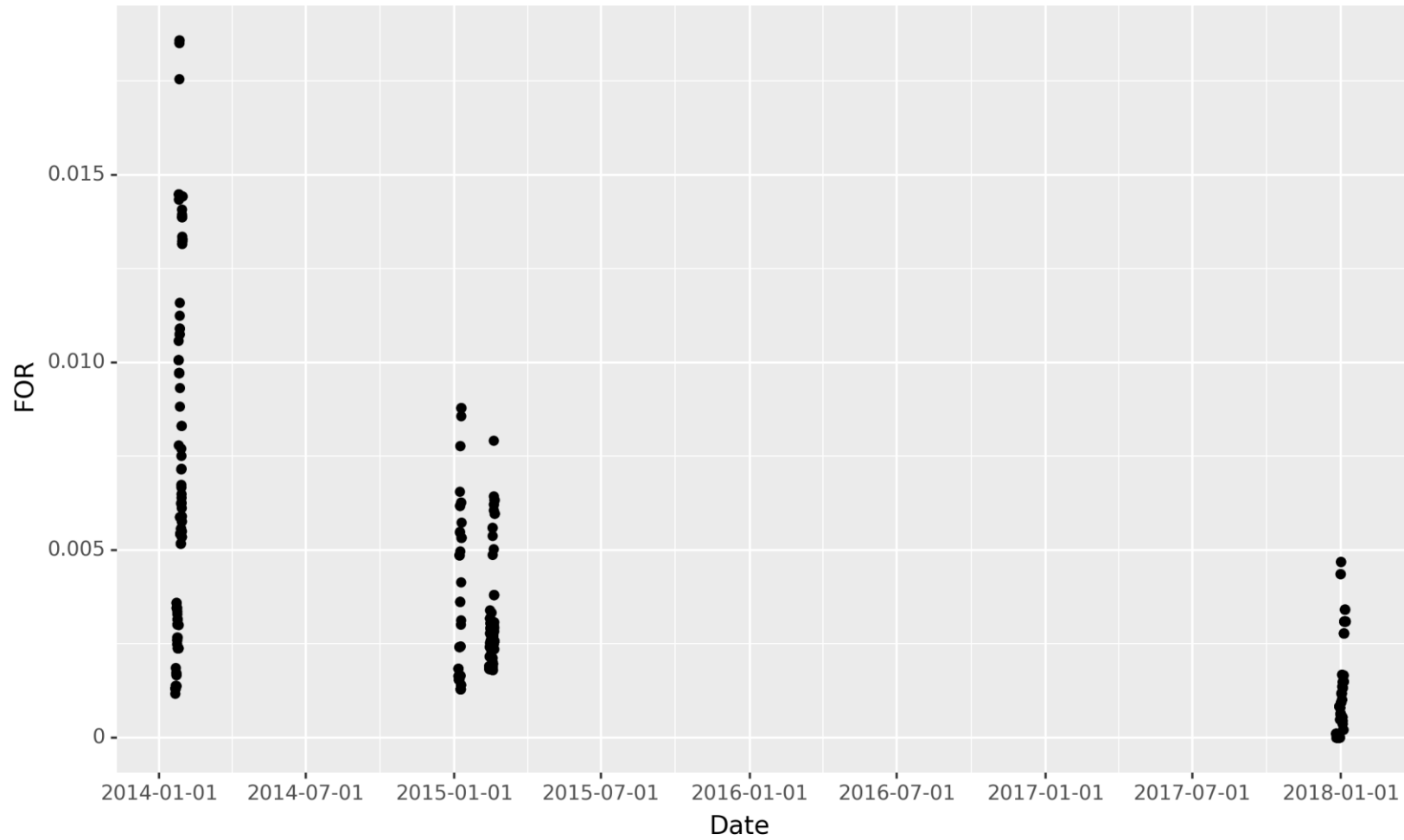
Cold Snap	Start	Stop	Duration
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2	Jan. 6, 2015	Jan. 10, 2015	5 Days
3	Feb. 13, 2015	Feb. 20, 2015	8 Days
4	Dec. 26, 2017	Jan. 7, 2018	13 Days

$$FOR = \frac{\text{MW Forced Out}}{\text{Total Installed Nameplate}}$$

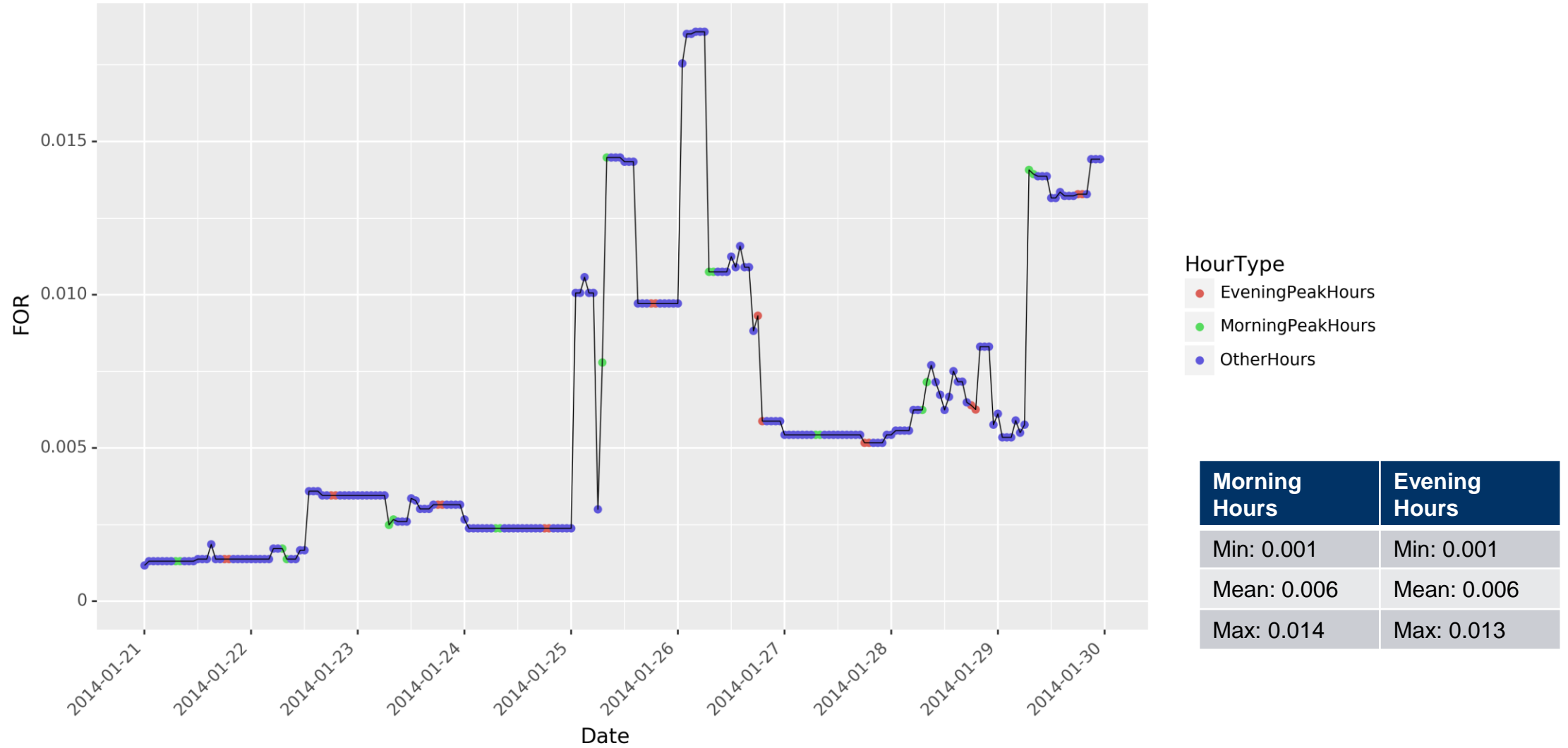
For coal, natural gas, nuclear, hydro, and oil resources, the forced outage rate serves as an indicator of the degree of unavailability for a set of resources

Winter Peak Hours:

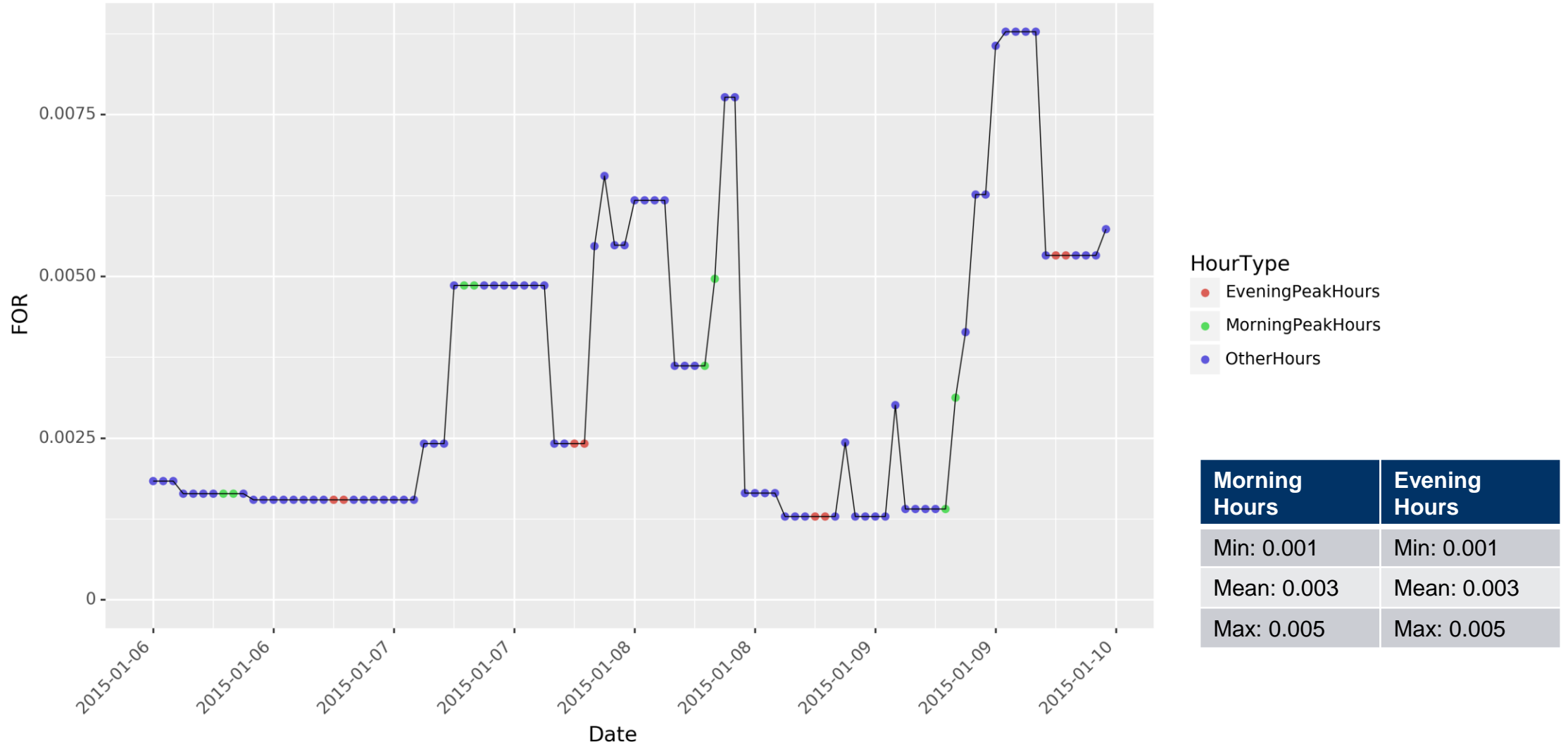
AM Peak	PM Peak
HE08 & HE09	HE19 & HE20



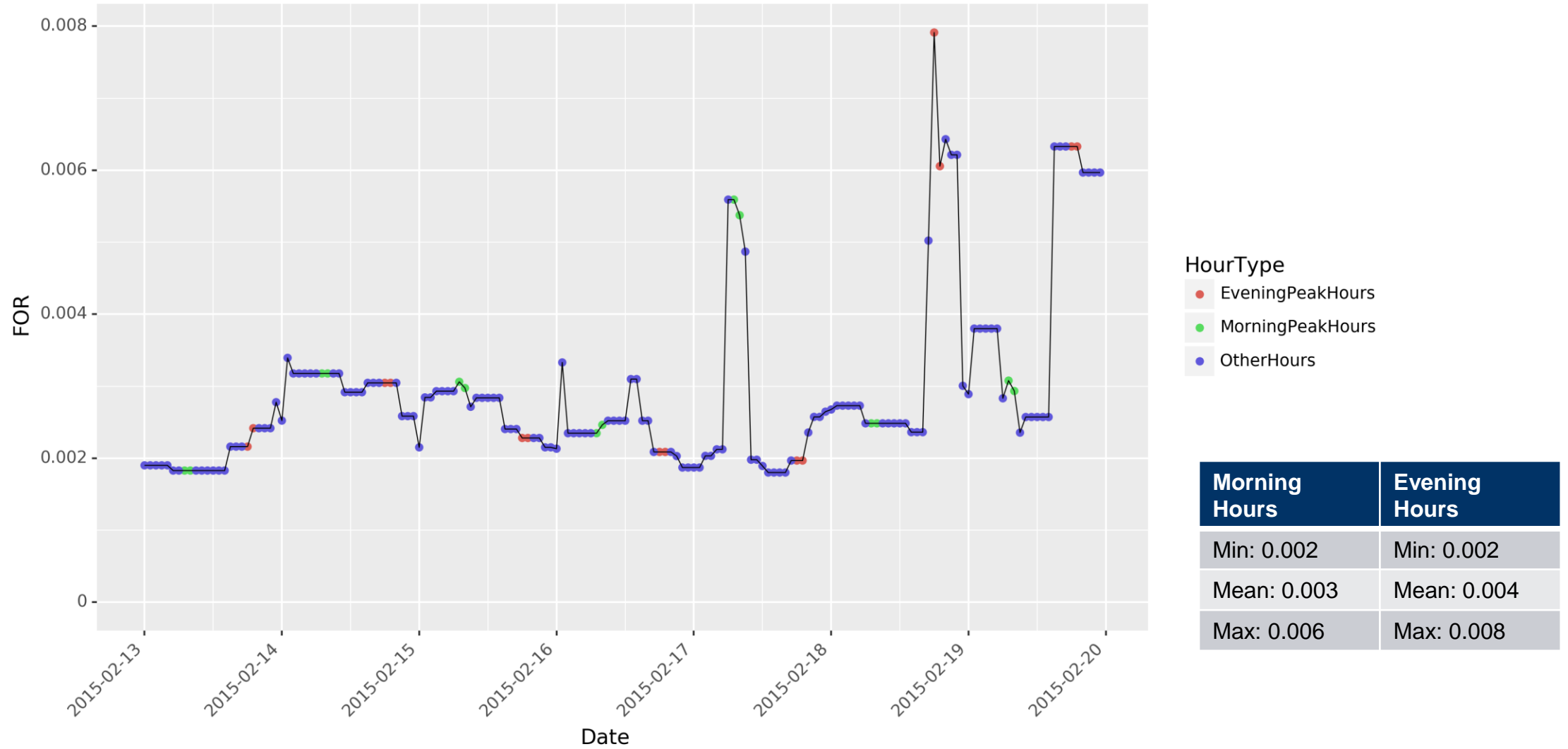
Coal RR-FOR (01/21/14 – 01/30/14)

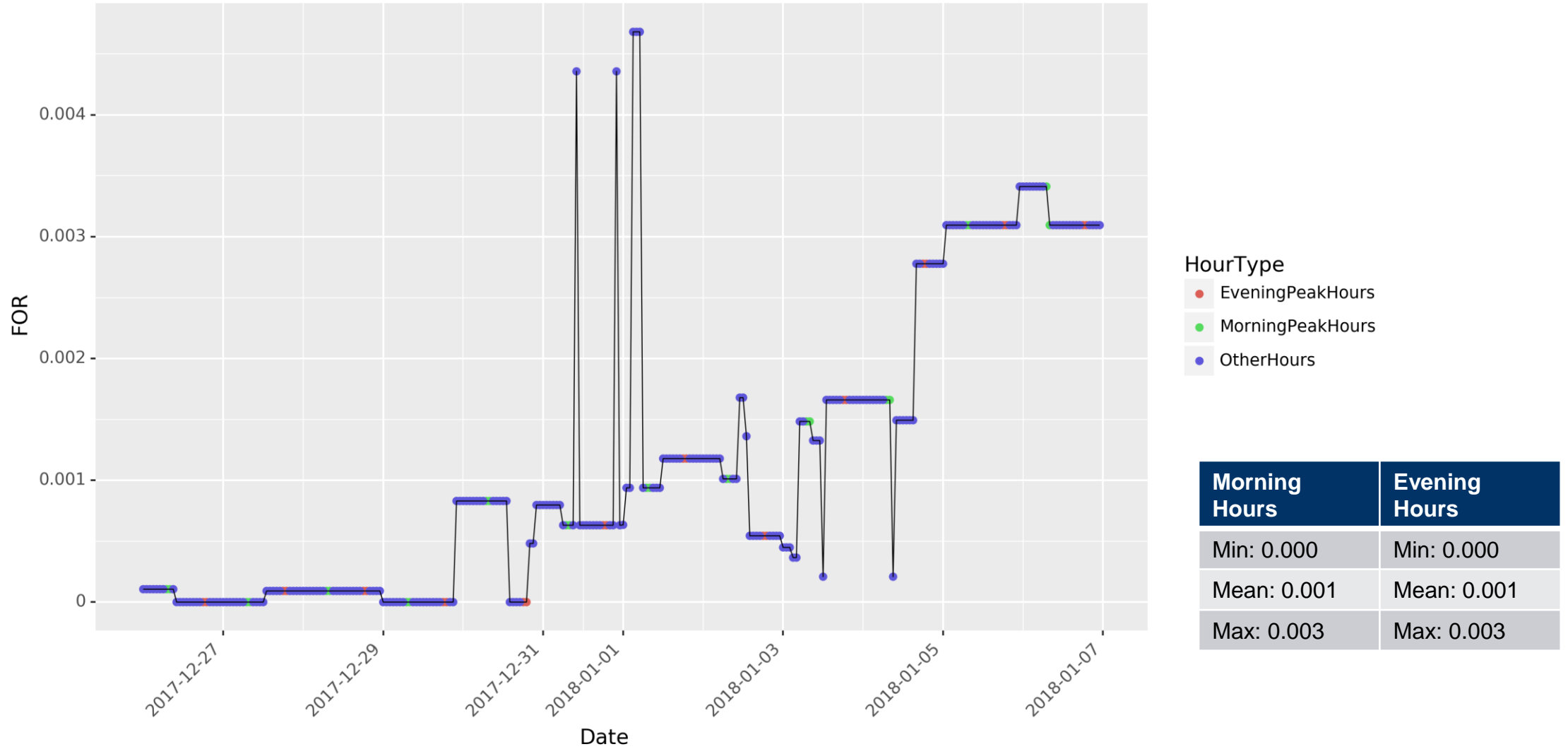


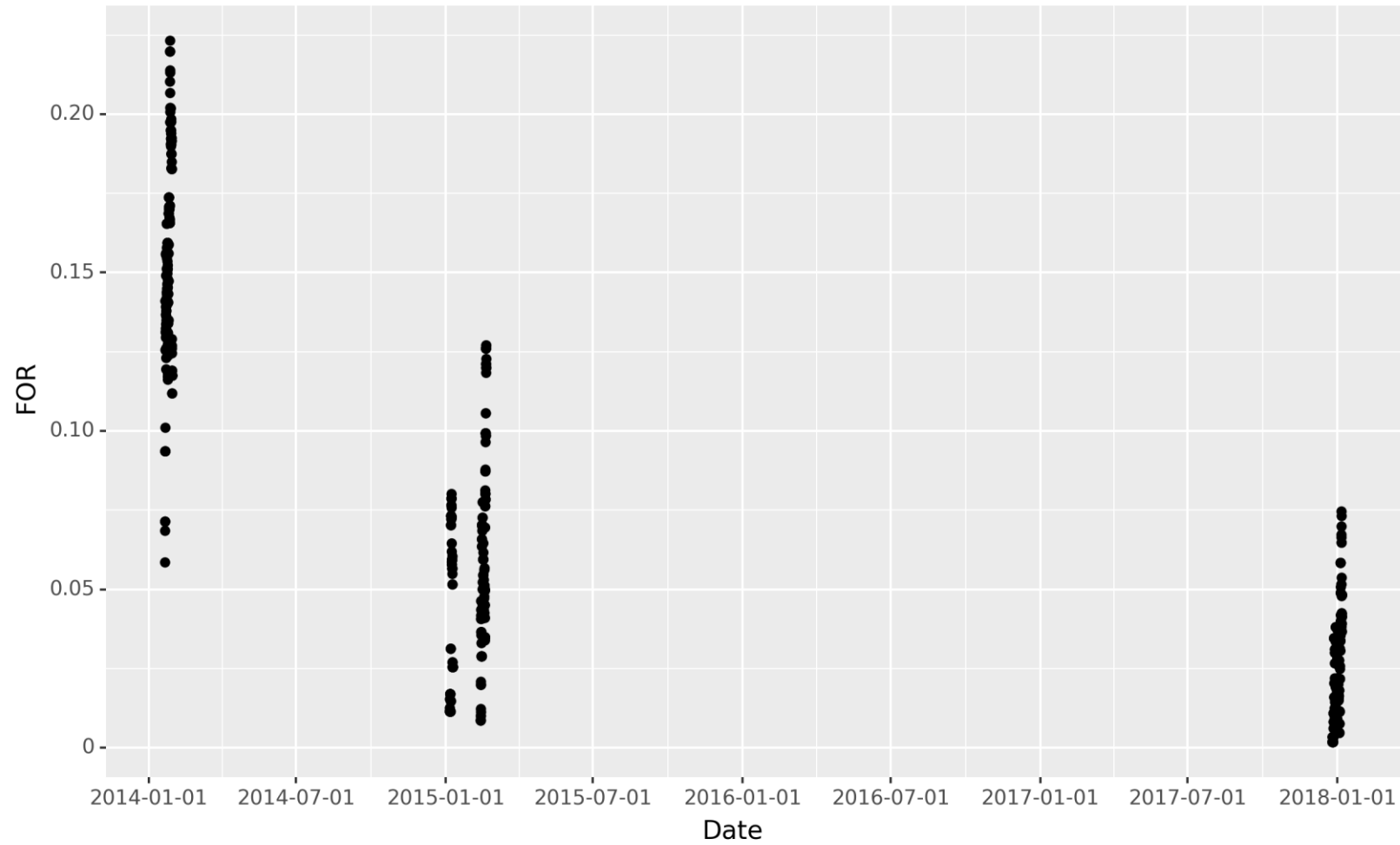
Coal RR-FOR (01/06/15 – 01/10/15)



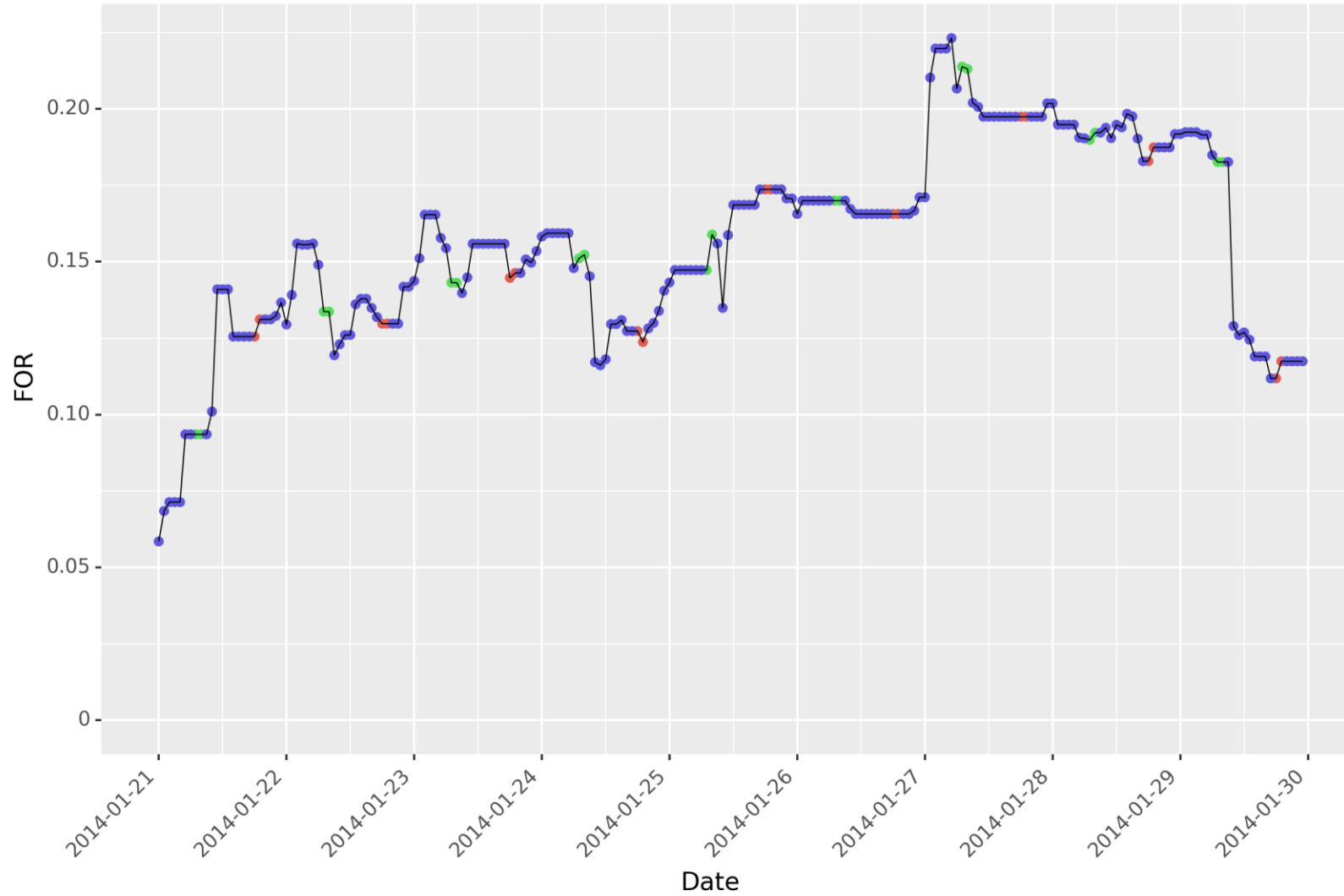
Coal RR-FOR (02/13/15 – 02/20/15)







Natural Gas RR-FOR (01/21/14 – 01/30/14)

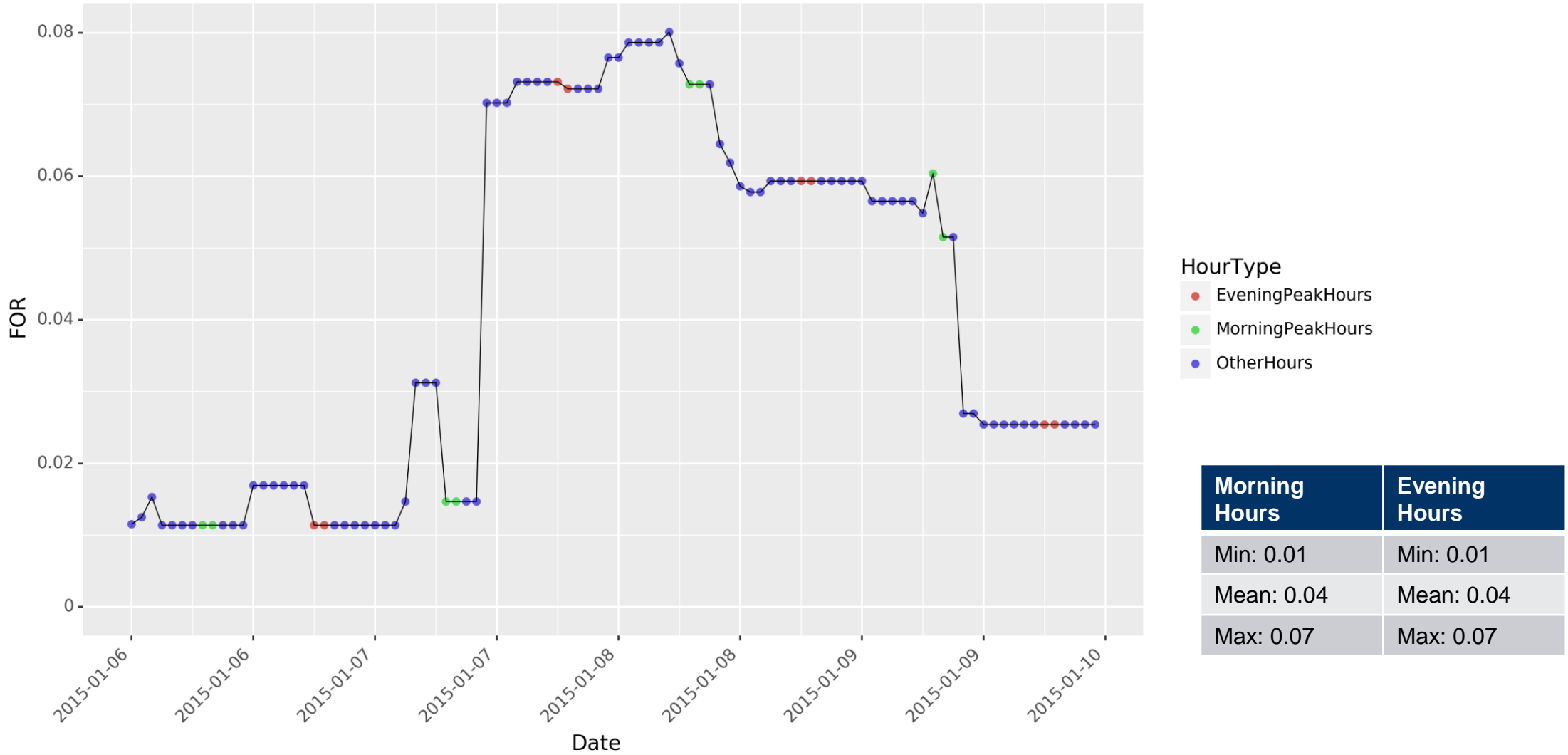


HourType

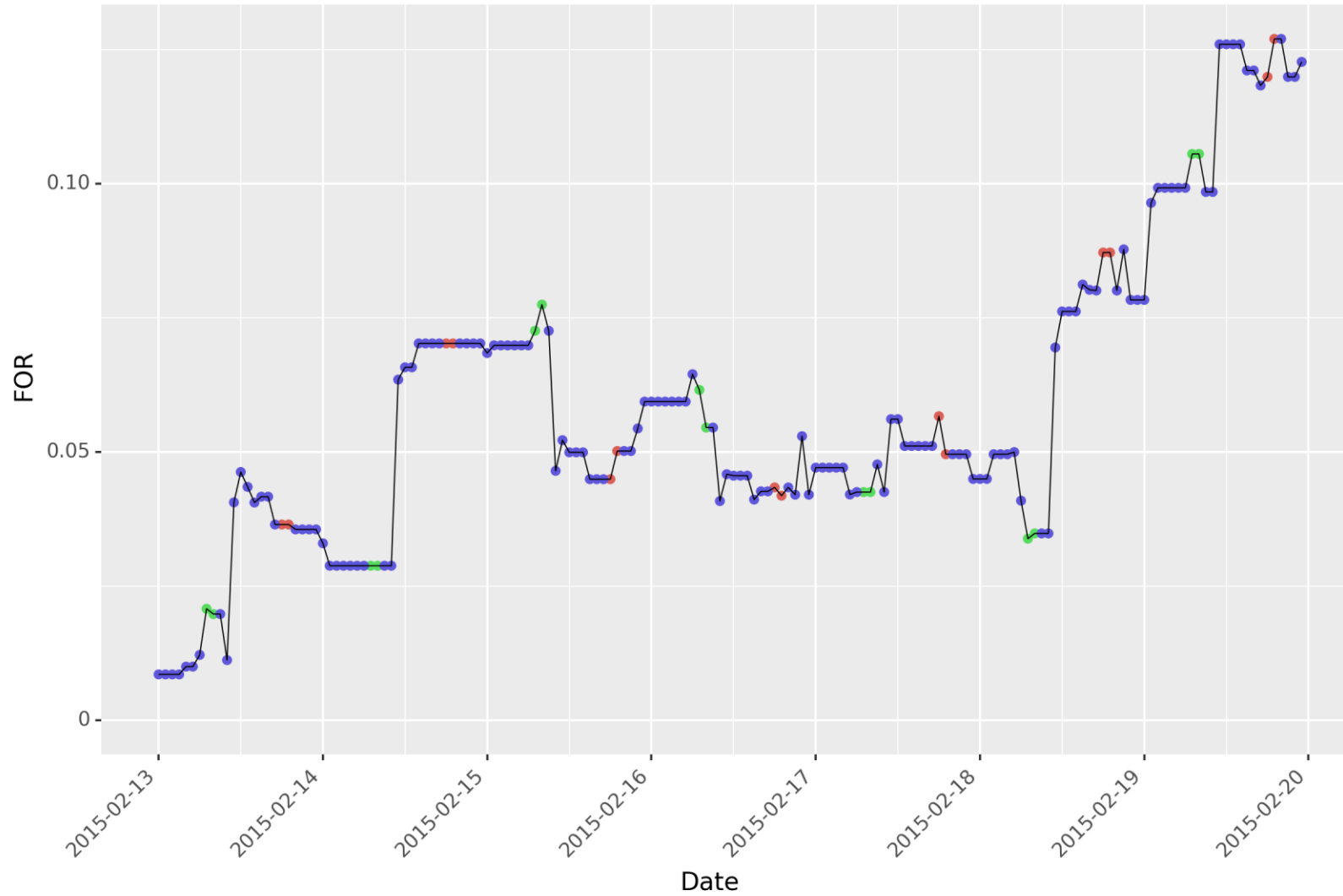
- EveningPeakHours
- MorningPeakHours
- OtherHours

Morning Hours	Evening Hours
Min: 0.09	Min: 0.11
Mean: 0.16	Mean: 0.15
Max: 0.21	Max: 0.20

Natural Gas RR-FOR (01/06/15 – 01/10/15)



Natural Gas RR-FOR (02/13/15 – 02/20/15)

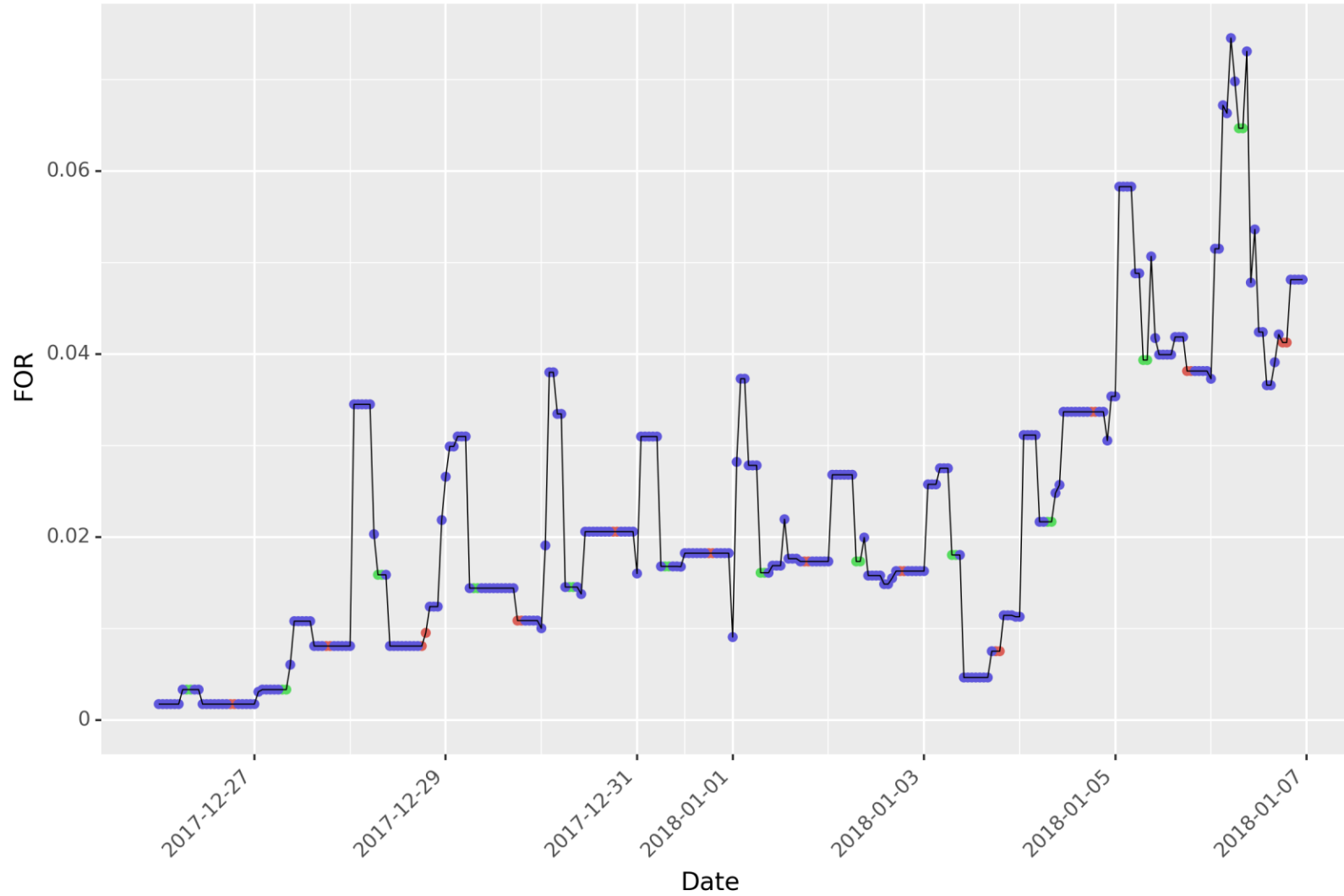


HourType

- EveningPeakHours
- MorningPeakHours
- OtherHours

Morning Hours	Evening Hours
Min: 0.02	Min: 0.04
Mean: 0.05	Mean: 0.07
Max: 0.11	Max: 0.13

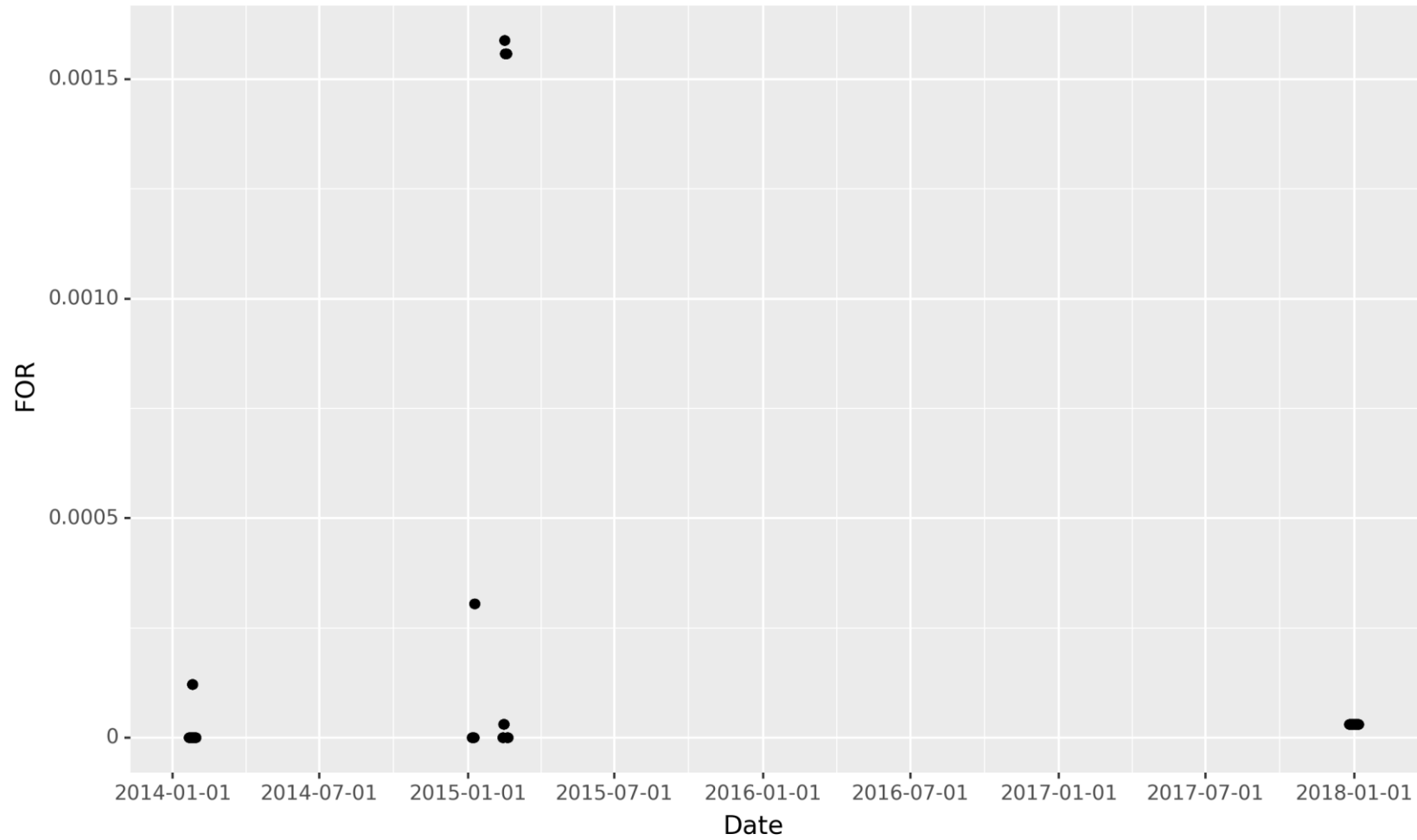
Natural Gas RR-FOR (12/26/17 – 01/07/18)



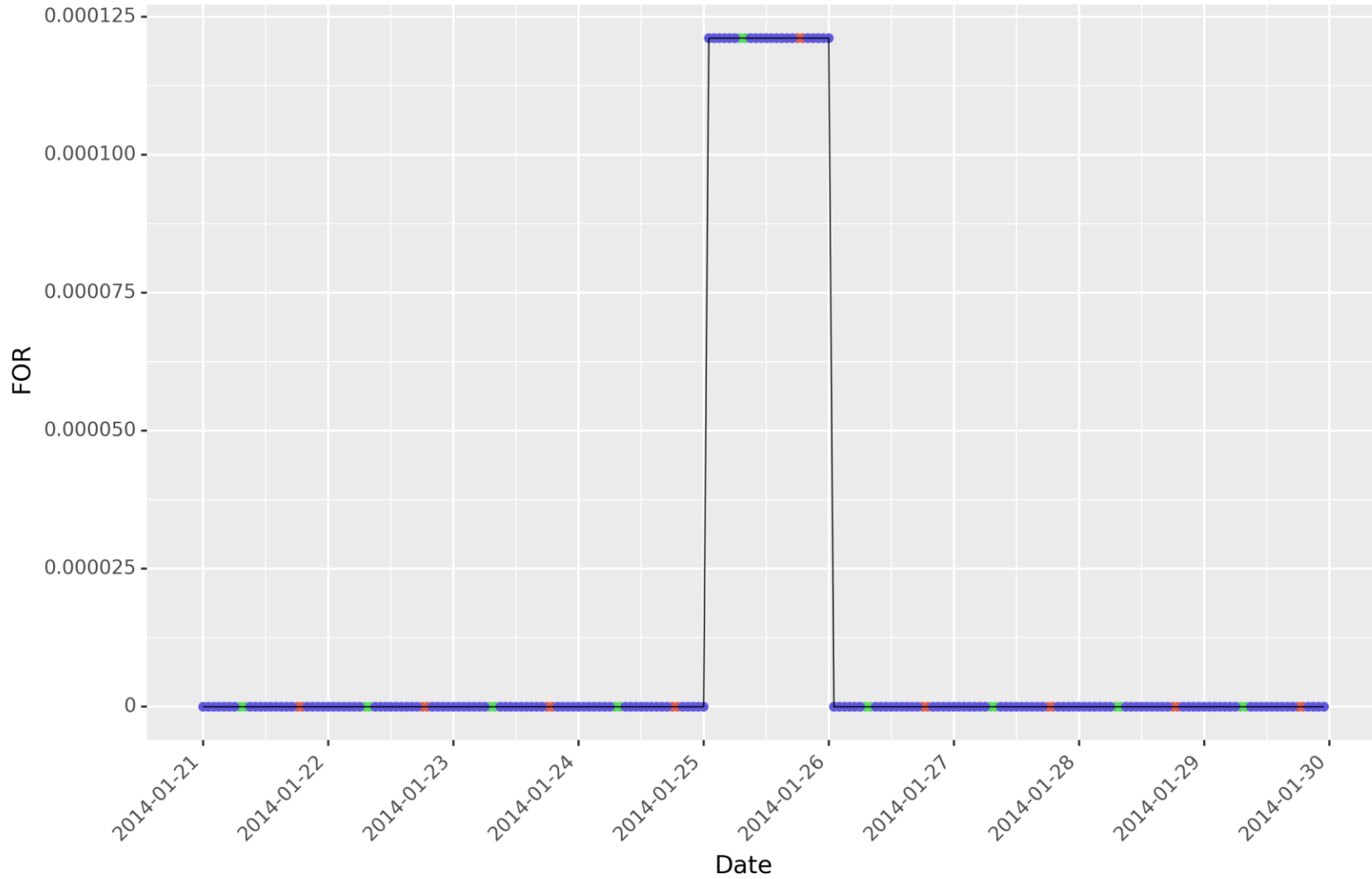
HourType

- EveningPeakHours
- MorningPeakHours
- OtherHours

Morning Hours	Evening Hours
Min: 0.003	Min: 0.002
Mean: 0.02	Mean: 0.02
Max: 0.07	Max: 0.04



Nuclear RR-FOR (01/21/14 – 01/30/14)

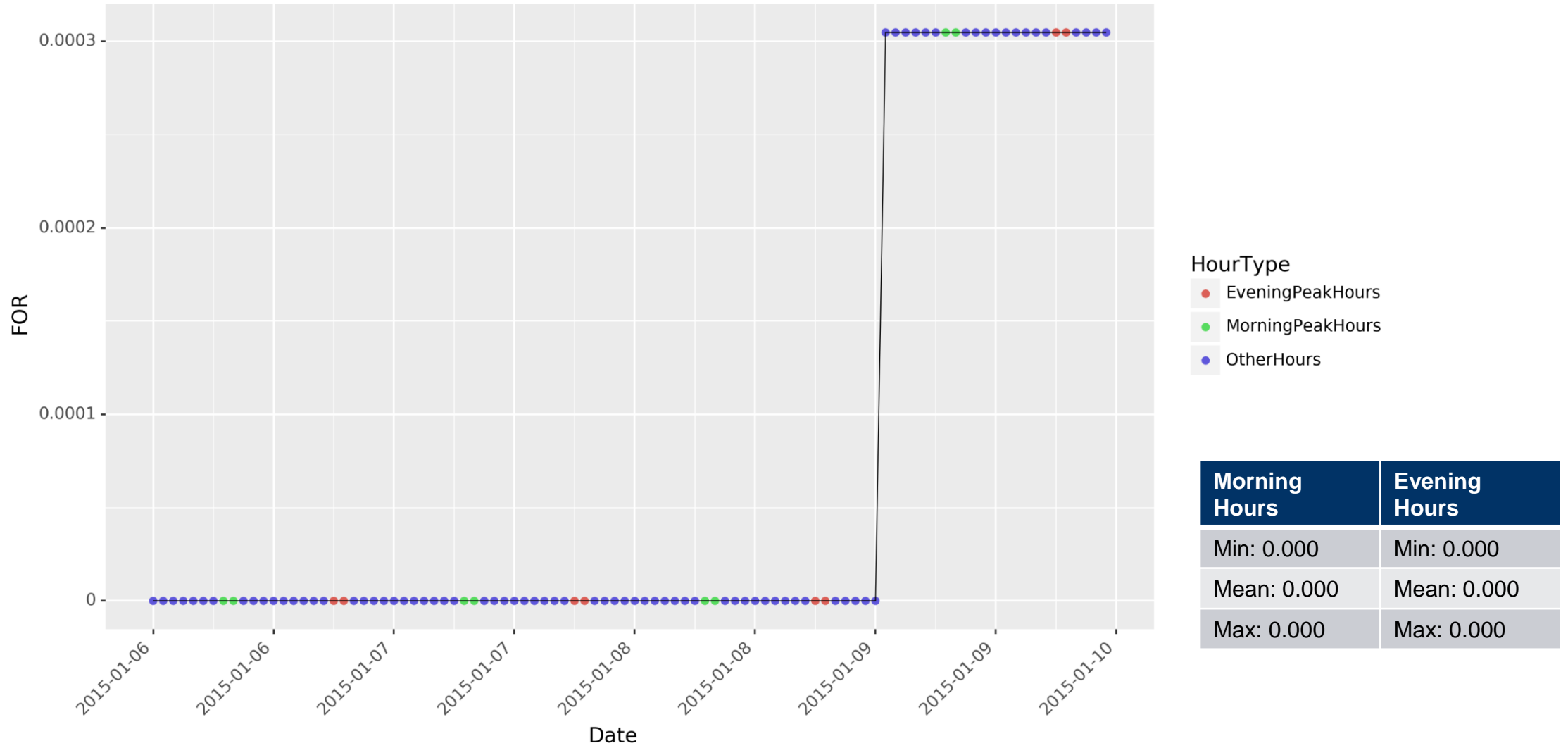


HourType

- EveningPeakHours
- MorningPeakHours
- OtherHours

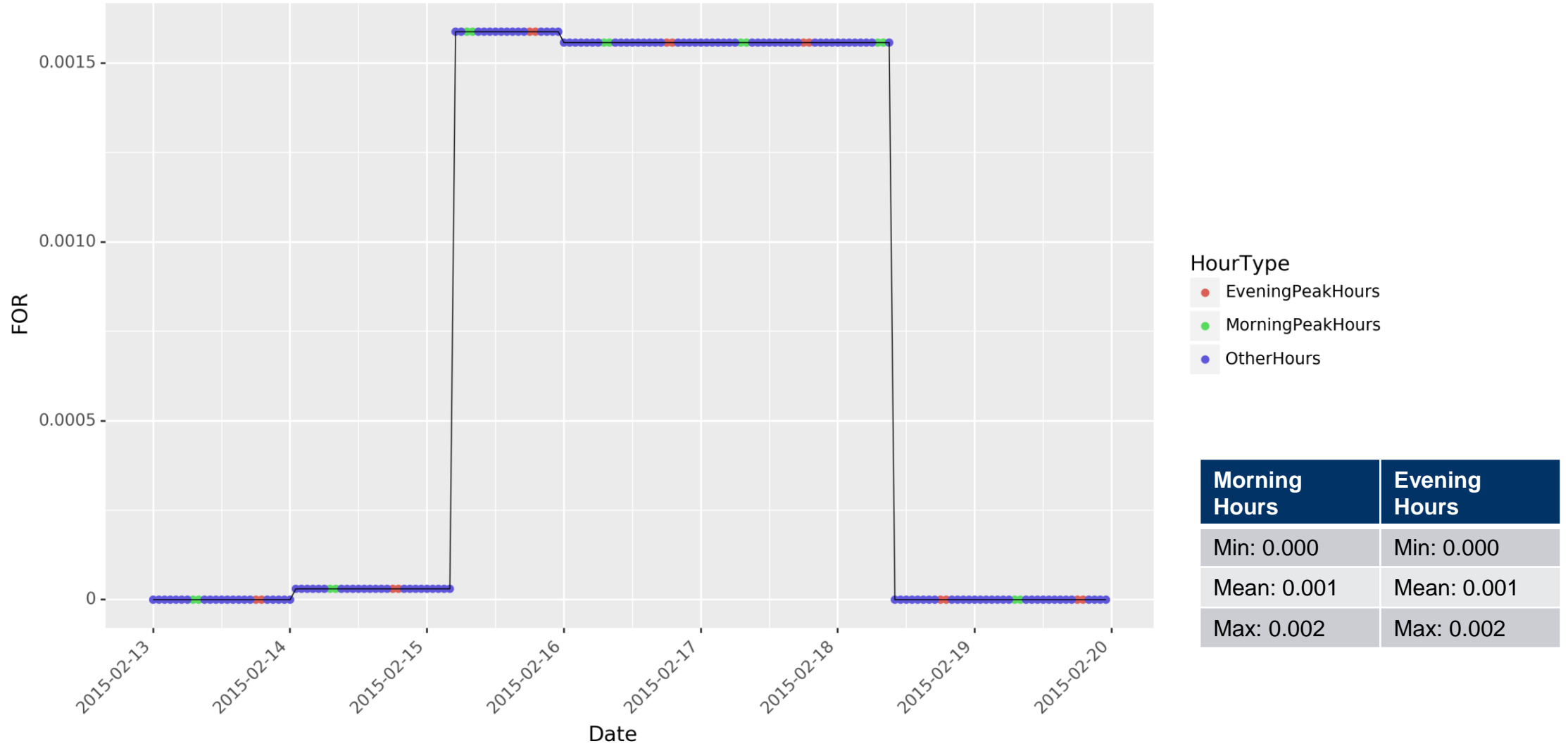
Morning Hours	Evening Hours
Min: 0.000	Min: 0.000
Mean: 0.000	Mean: 0.000
Max: 0.000	Max: 0.000

Nuclear RR-FOR (01/06/15 – 01/10/15)

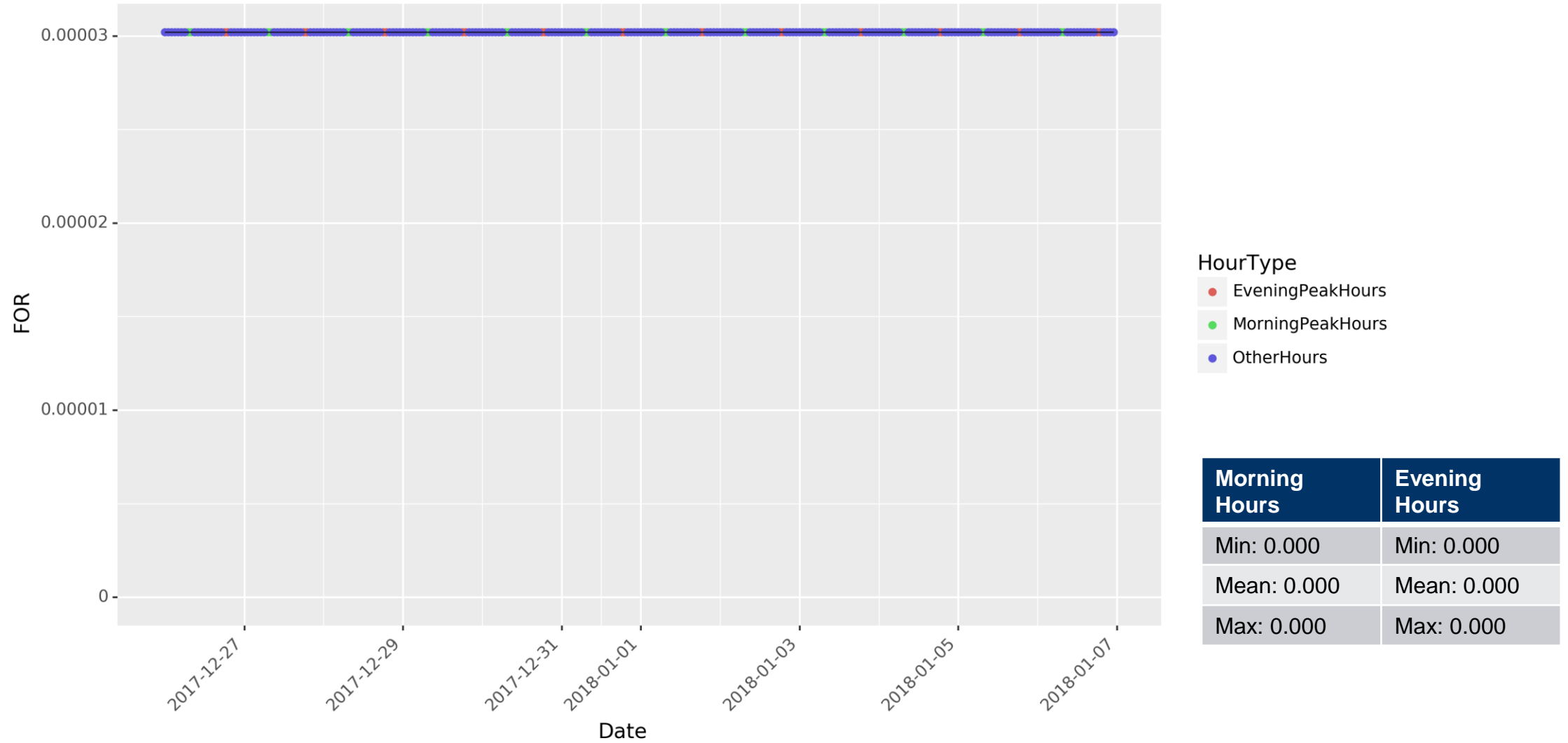


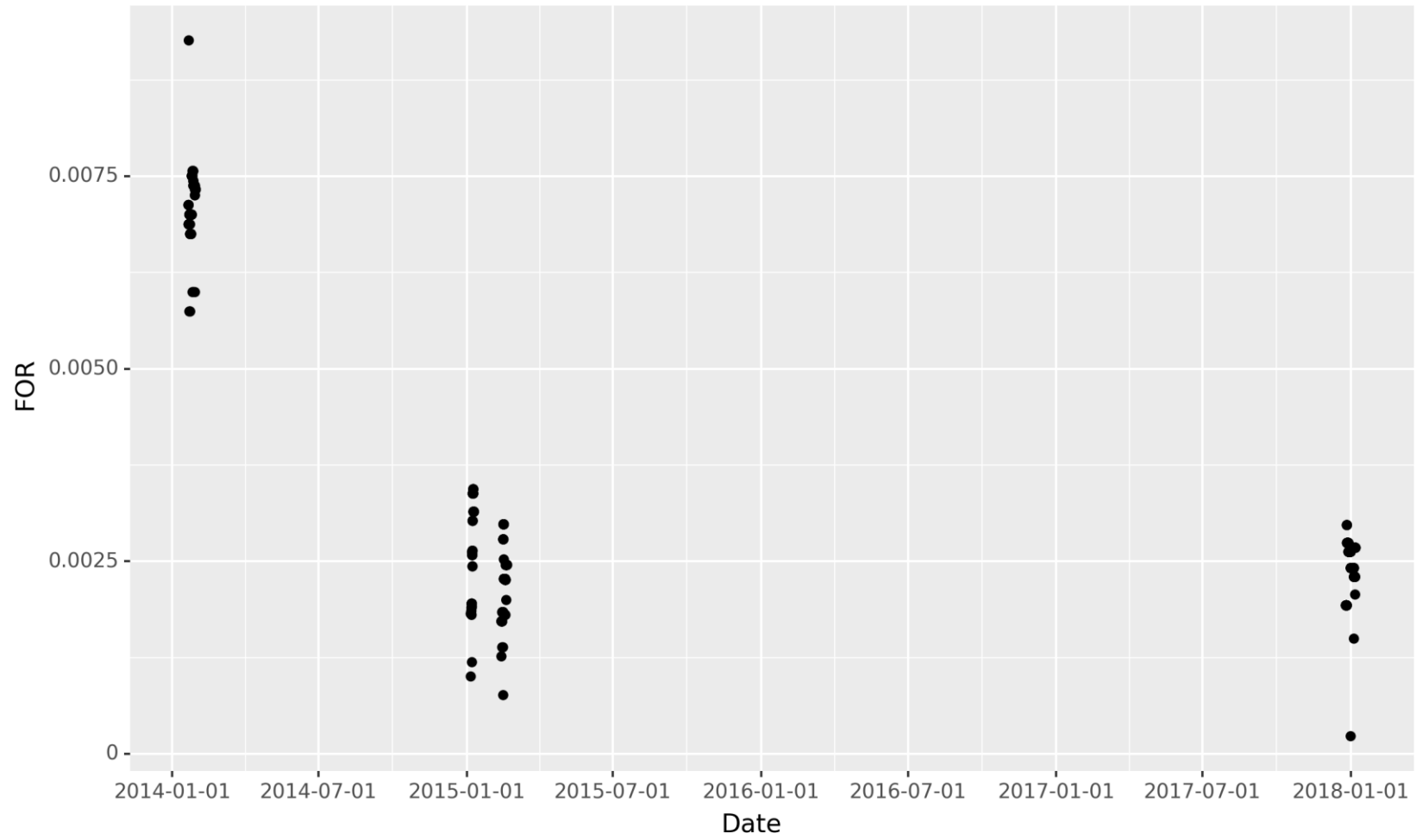
Morning Hours	Evening Hours
Min: 0.000	Min: 0.000
Mean: 0.000	Mean: 0.000
Max: 0.000	Max: 0.000

Nuclear RR-FOR (02/13/15 – 02/20/15)

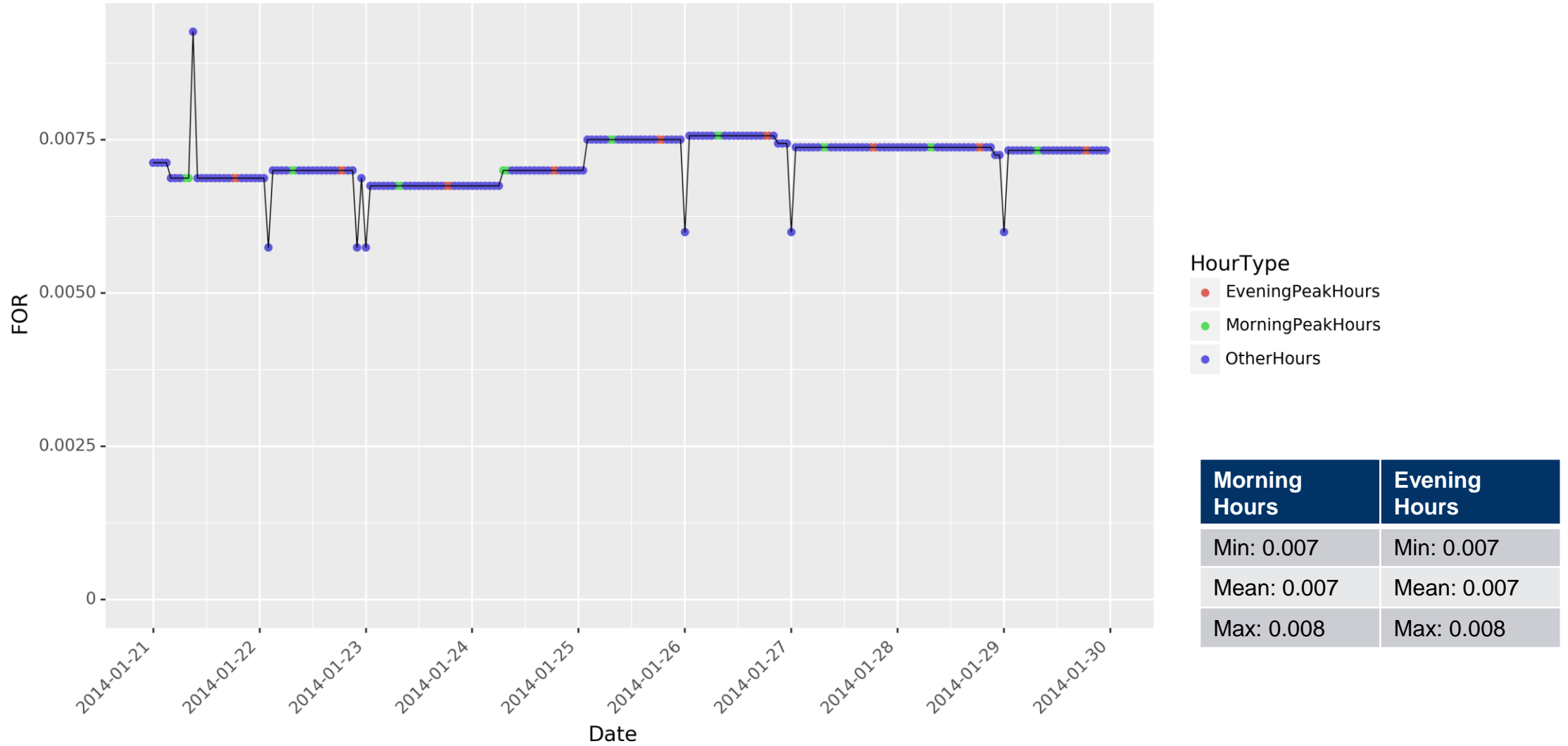


Nuclear RR-FOR (12/26/17 – 01/07/18)

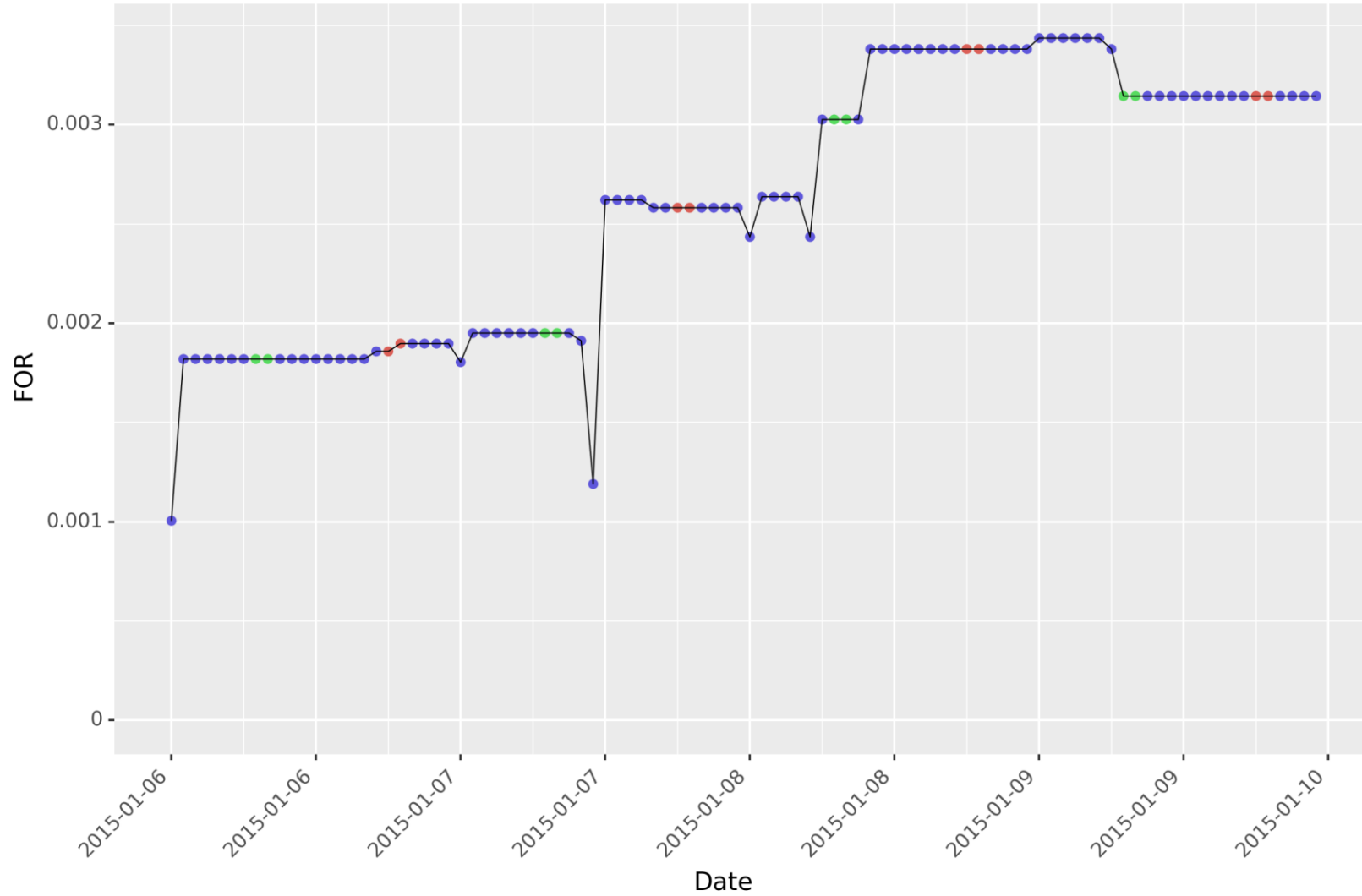




Hydro RR-FOR (01/21/14 – 01/30/14)



Hydro RR-FOR (01/06/15 – 01/10/15)

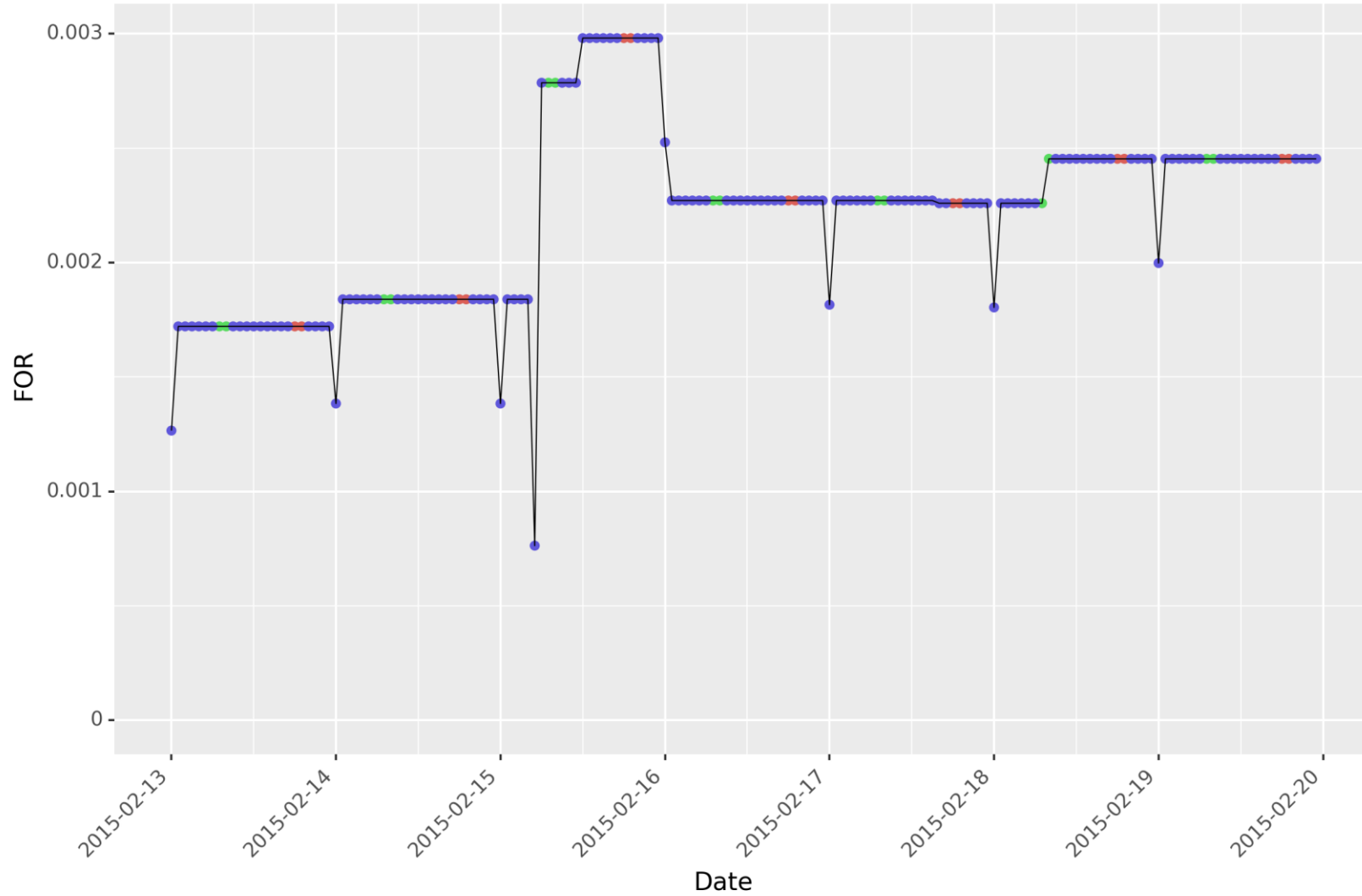


HourType

- EveningPeakHours
- MorningPeakHours
- OtherHours

Morning Hours	Evening Hours
Min: 0.002	Min: 0.002
Mean: 0.002	Mean: 0.003
Max: 0.003	Max: 0.003

Hydro RR-FOR (02/13/15 – 02/20/15)

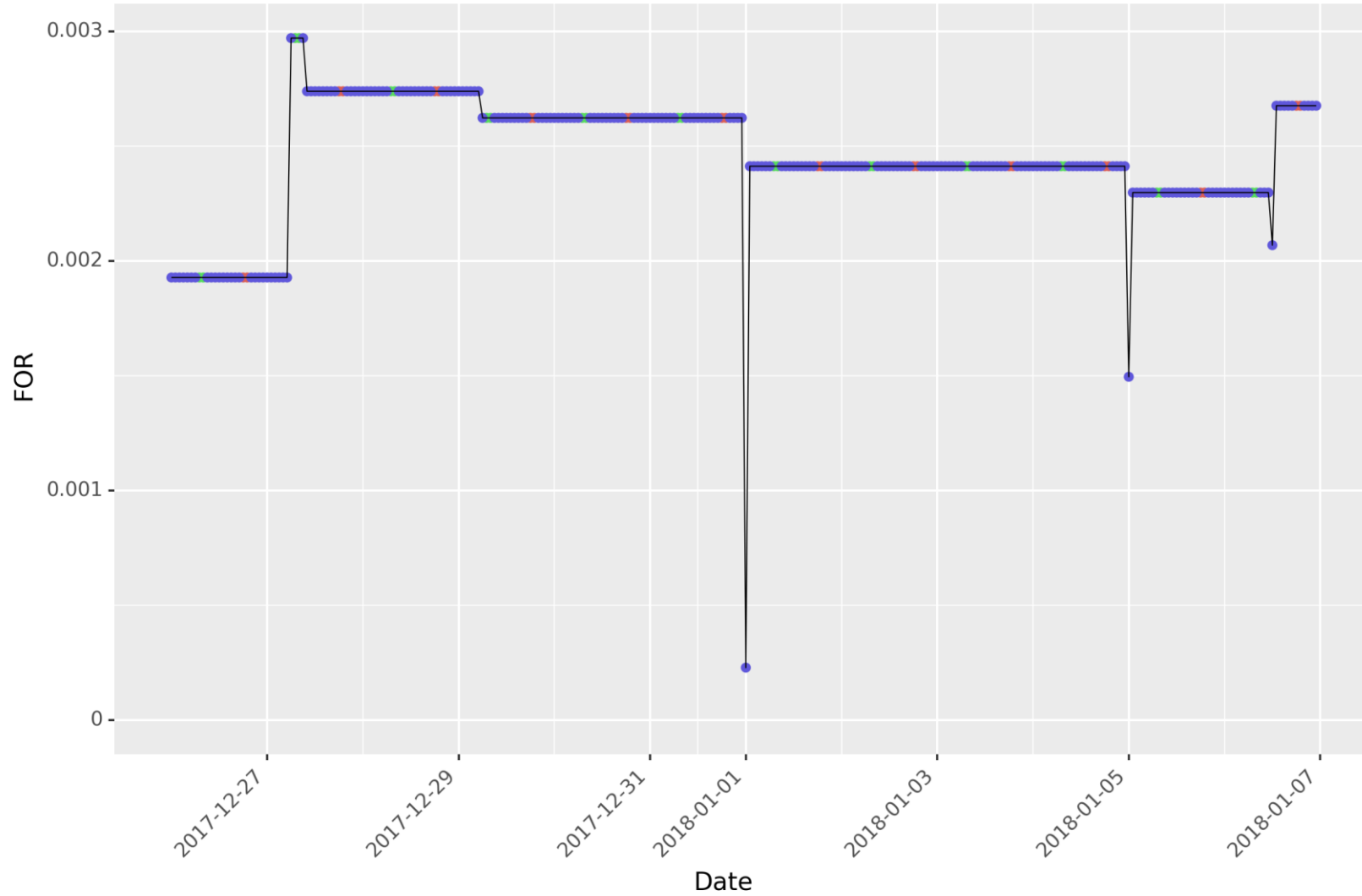


HourType

- EveningPeakHours
- MorningPeakHours
- OtherHours

Morning Hours	Evening Hours
Min: 0.002	Min: 0.002
Mean: 0.002	Mean: 0.002
Max: 0.003	Max: 0.003

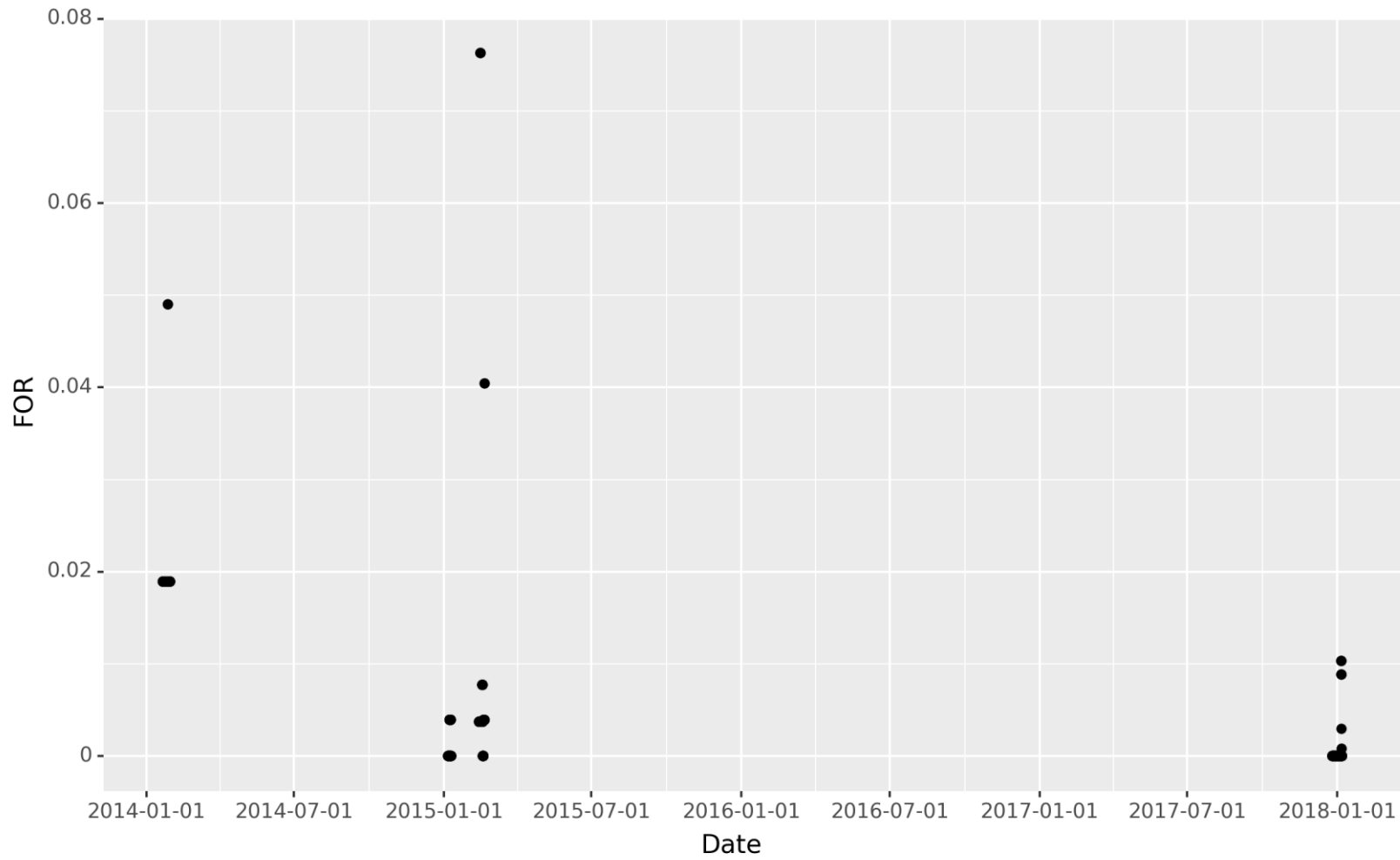
Hydro RR-FOR (12/26/17 – 01/07/18)



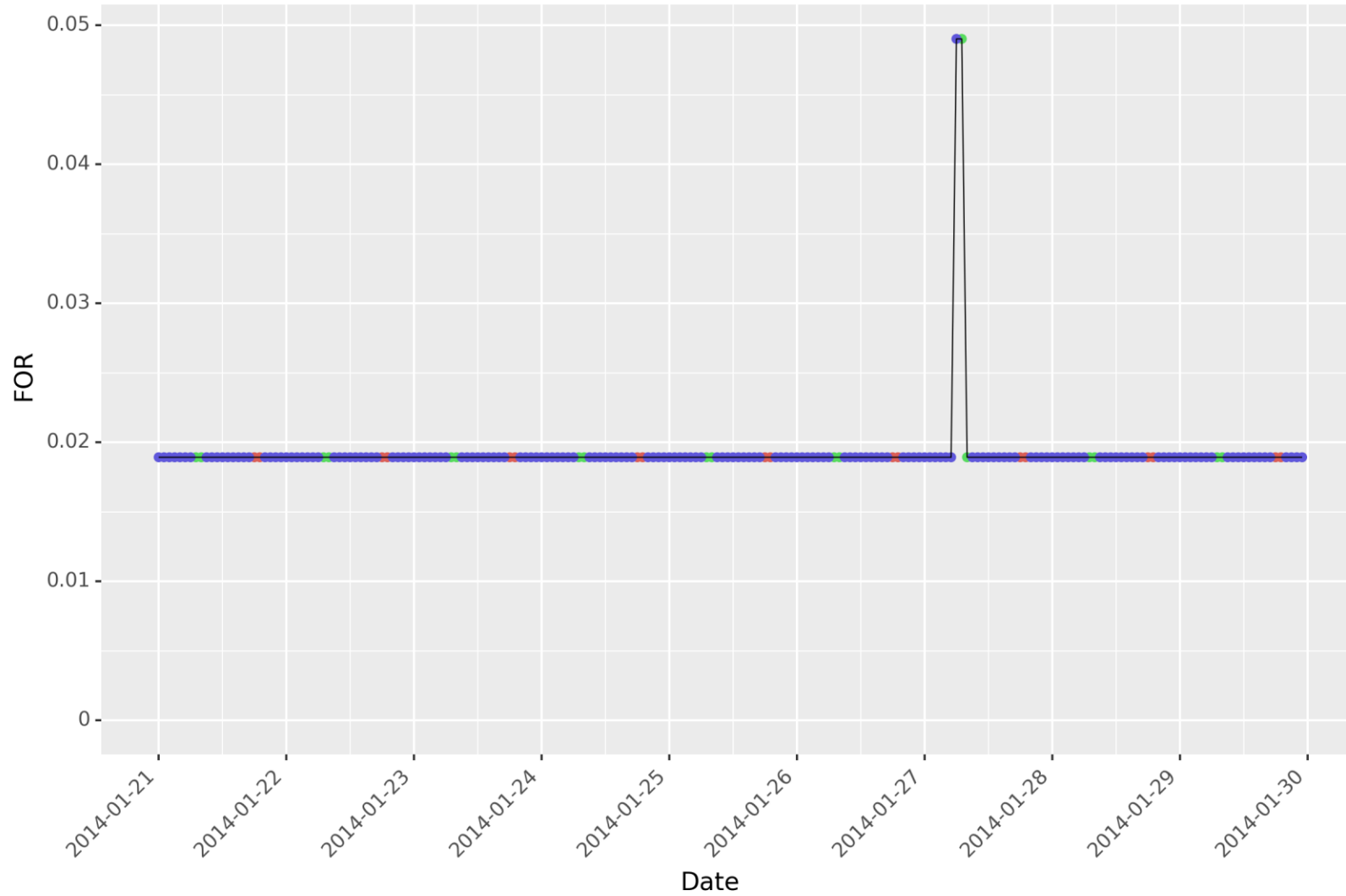
HourType

- EveningPeakHours
- MorningPeakHours
- OtherHours

Morning Hours	Evening Hours
Min: 0.002	Min: 0.002
Mean: 0.002	Mean: 0.002
Max: 0.003	Max: 0.003



Oil RR-FOR (01/21/14 – 01/30/14)

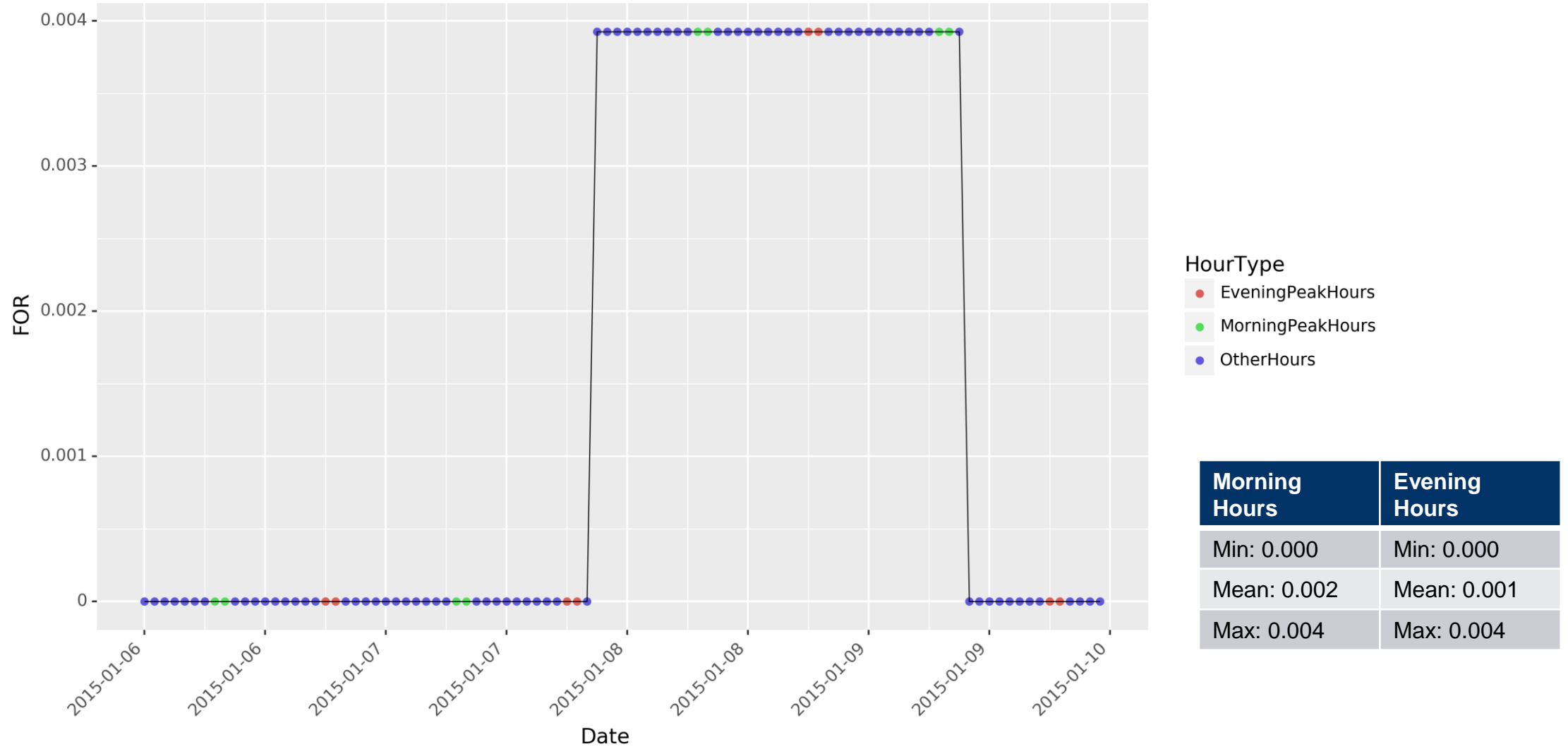


HourType

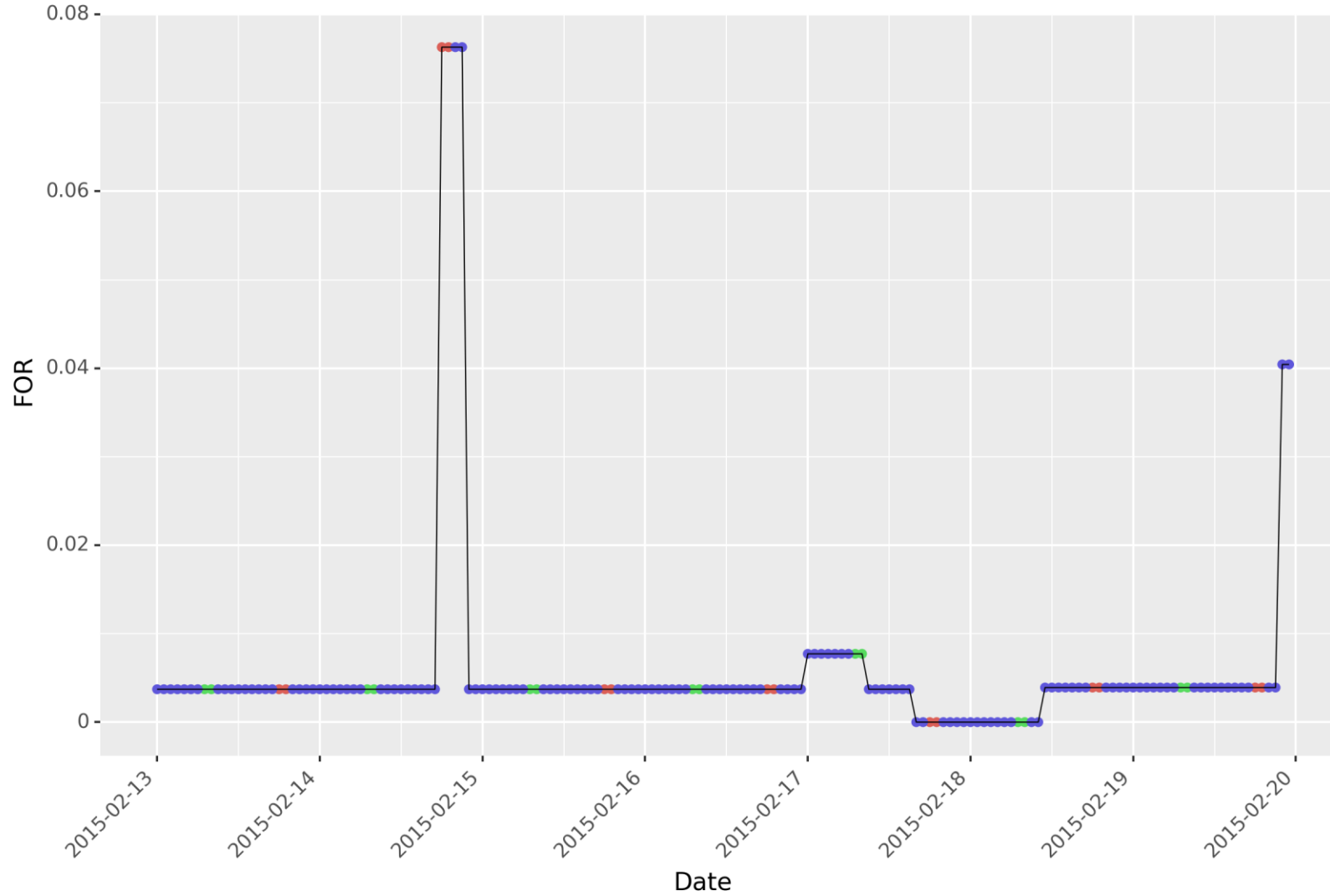
- EveningPeakHours
- MorningPeakHours
- OtherHours

Morning Hours	Evening Hours
Min: 0.019	Min: 0.019
Mean: 0.021	Mean: 0.019
Max: 0.049	Max: 0.019

Oil RR-FOR (01/06/15 – 01/10/15)



Oil RR-FOR (02/13/15 – 02/20/15)

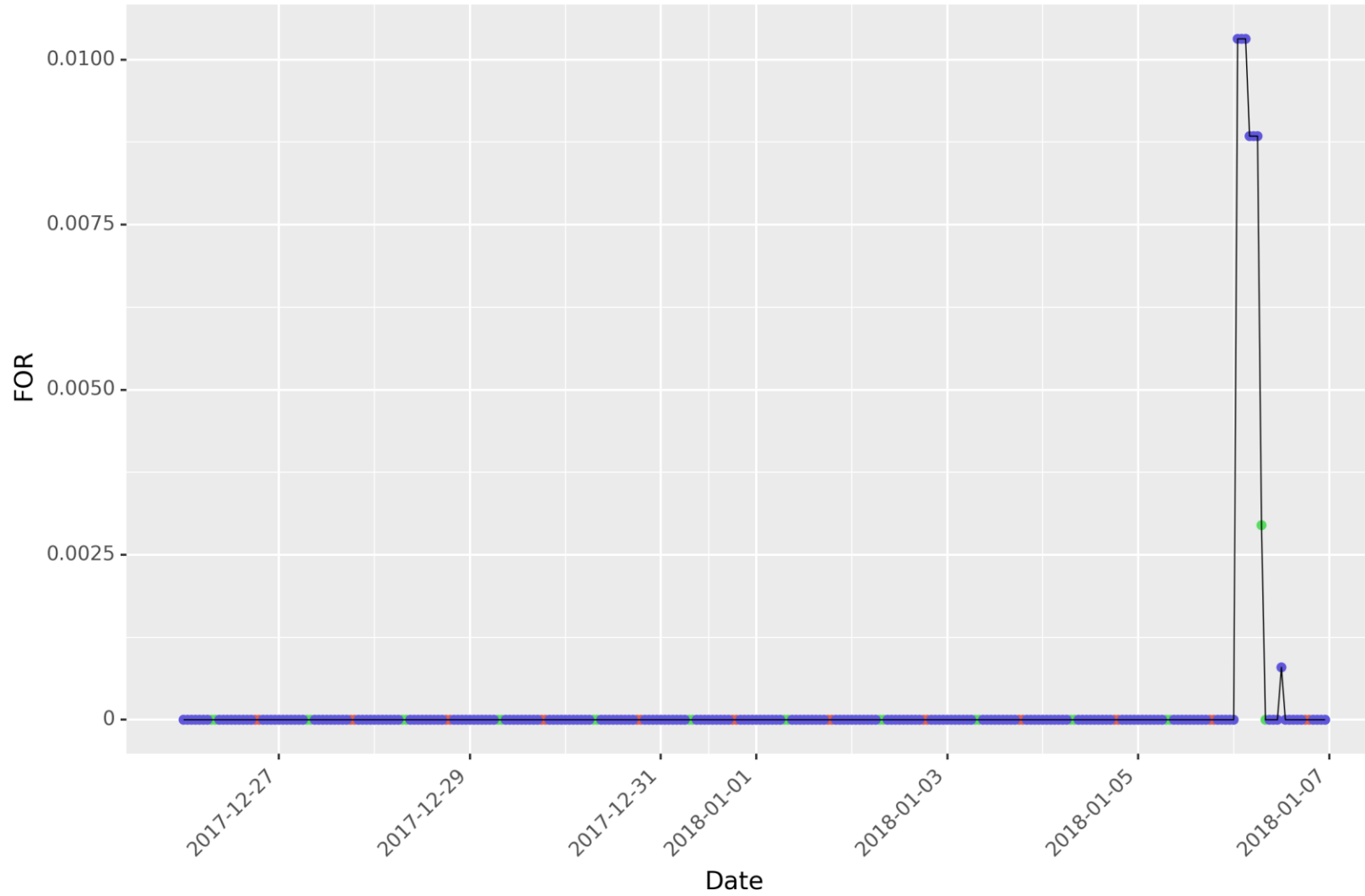


HourType

- EveningPeakHours
- MorningPeakHours
- OtherHours

Morning Hours	Evening Hours
Min: 0.000	Min: 0.000
Mean: 0.004	Mean: 0.014
Max: 0.008	Max: 0.076

Oil RR-FOR (12/26/17 – 01/07/18)



HourType

- EveningPeakHours
- MorningPeakHours
- OtherHours

Morning Hours	Evening Hours
Min: 0.000	Min: 0.000
Mean: 0.000	Mean: 0.000
Max: 0.003	Max: 0.000

Scenario Development

Scenario Analysis	Winter Load	Renewable Profiles	Relevant Risk Forced Outages	Other Forced Outages
Phase 1	Typical <ul style="list-style-type: none"> • 50/50 peak (134,976 MW) • 2011/12 load profile Extreme Winter <ul style="list-style-type: none"> • 95/5 peak (147,721 MW) • 2017/18 load profile 14 day study period	2017/18 winter profiles, scaled to nameplate capacity in portfolio	Explicitly modeled sensitivities for fuel delivery risks: oil refueling, non-firm gas availability, pipeline disruptions	Forced outage rates using GADS cause codes not used in relevant risks or sensitivities
Phase 2	Load shapes consistent with selected cold snaps	Profile from cold snap, scaled to nameplate capacity in portfolio	Relevant Risk Forced Outages Rates from cold snap scaled to portfolio Sensitivities for discrete occurrences of risks outside of historical forced outage dataset	

Phase 1 portfolios for all scenarios: Announced (25.8% IRM), Escalated 1 (15.8% IRM), Escalated 2 (15.8% IRM)

Approach for Phase 2 Scenarios Using Relevant Risk Data

1. Selected cold snaps from analysis of winter weather:
 - Jan 21, 2014 through Jan 30, 2014 (10 days)
 - Jan 6, 2015 through Jan 10, 2015 (5 days)
 - Feb 13, 2015 through Feb 20, 2015 (8 days)
 - Dec 26, 2017 though Jan 7, 2018 (13 days)

2. For each cold snap, will use associated:
 - a) Resource-Type Specific Forced Outage profiles to address the relevant risks
 - b) Renewable output profiles
 - c) Forced outage rates using GADS cause codes not used in relevant risks or sensitivities

3. Sensitivities to model discrete occurrences of risks outside of historical forced outage dataset (pipeline disruptions, rail disruption, nuclear regulatory shutdown, etc.)

Technical Appendix: Fuel Specific Cause Code Combinations

Cause Code	Description
9200 & 9201	High Ash Content (OMC & non-OMC)
9210 & 9211	Low Grindability (OMC & non-OMC)
9220 & 9221	High Sulfur Content (OMC & non-OMC)
9230 & 9231	High Vanadium Content (OMC & non-OMC)
9240 & 9241	High Sodium Content (OMC & non-OMC)
9250 & 9251	Low BTU Coal (OMC & non-OMC)
9270 & 9271	Wet Coal (OMC & non-OMC)
9280 & 9281	Frozen Coal (OMC & non-OMC)



Coal Applicable Common Cause Codes

Cause Code	Description
9130	Lack of fuel where operators is not in control of contracts, supply lines, or delivery of fuels
9131	Lack of fuel (interruptible supple of fuel part of fuel contract)
9290 & 9291	Other Fuel Quality Problems (OMC & non-OMC)
7112 & 3274	Ice blockages at intake structures
7199	Other water supply/discharge problems
9135	Lack of Water
3273	Debris in circulating water from outside sources
3280	High Circulating Water Temperature
9000, 9001, 9020, 9025, 9030, 9031, 9035, 9040	Natural Disasters (Flood, Drought, Lightning, Geomagnetic Disturbance, Earthquake, Tornado, Hurricane, Other Catastrophe)
9134	Fuel Conservation

Cause Code	Description
9205	Poor quality natural gas fuel, low heat content



Natural Gas Applicable Common Cause Codes

Cause Code	Description
9130	Lack of fuel where operators is not in control of contracts, supply lines, or delivery of fuels
9131	Lack of fuel (interruptible supple of fuel part of fuel contract)
9290 & 9291	Other Fuel Quality Problems (OMC & non-OMC)
7112 & 3274	Ice blockages at intake structures
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9134	Fuel Conservation

Cause Code	Description
9500	Regulatory (nuclear) proceedings and hearings – regulatory agency initiated
9502	Regulatory (nuclear) proceedings and hearings – intervenor initiated
9710	Investigation of possible nuclear safety problems
2010	Fuel failure, including high activity in Reactor Coolant System or off-gas system
2030	Fuel limits – peaking factors
2032	Fuel limits – minimum critical power ratio (BWR units only)
2033	Fuel limits – maximum average planar linear heat generation rate (BWR units only)
2037	Other fuel limits (excluding core coast down, conservation, or stretch)



Nuclear Applicable Common Cause Codes

Cause Code	Description
9130	Lack of fuel where operators is not in control of contracts, supply lines, or delivery of fuels
9131	Lack of fuel (interruptible supple of fuel part of fuel contract)
9290 & 9291	Other Fuel Quality Problems (OMC & non-OMC)
7112 & 3274	Ice blockages at intake structures
7199	Other water supply/discharge problems
9135	Lack of Water
3273	Debris in circulating water from outside sources
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9000, 9001, 9020, 9025, 9030, 9031, 9035, 9040	Natural Disasters (Flood, Drought, Lightning, Geomagnetic Disturbance, Earthquake, Tornado, Hurricane, Other Catastrophe)
9134	Fuel Conservation

Cause Code	Description
7100	Upper reservoir dams and dikes
7101	Lower reservoir dams and dikes
7102	Auxiliary reservoir dams and dikes
7110	Intake channel or flume (excluding trash racks)
7111	Intake tunnel



Hydro Applicable Common Cause Codes

Cause Code	Description
9130	Lack of fuel where operators is not in control of contracts, supply lines, or delivery of fuels
9131	Lack of fuel (interruptible supple of fuel part of fuel contract)
9290 & 9291	Other Fuel Quality Problems (OMC & non-OMC)
7112 & 3274	Ice blockages at intake structures
7199	Other water supply/discharge problems
9135	Lack of Water
3273	Debris in circulating water from outside sources
3280	High Circulating Water Temperature
9000, 9001, 9020, 9025, 9030, 9031, 9035, 9040	Natural Disasters (Flood, Drought, Lightning, Geomagnetic Disturbance, Earthquake, Tornado, Hurricane, Other Catastrophe)
9134	Fuel Conservation

Cause Code	Description
9260 & 9261	Low BTU oil (OMC & non-OMC)



Oil Applicable Common Cause Codes

Cause Code	Description
9130	Lack of fuel where operators is not in control of contracts, supply lines, or delivery of fuels
9131	Lack of fuel (interruptible supple of fuel part of fuel contract)
9290 & 9291	Other Fuel Quality Problems (OMC & non-OMC)
7112 & 3274	Ice blockages at intake structures
7199	Other water supply/discharge problems
9135	Lack of Water
3273	Debris in circulating water from outside sources
3280	High Circulating Water Temperature
9000, 9001, 9020, 9025, 9030, 9031, 9035, 9040	Natural Disasters (Flood, Drought, Lightning, Geomagnetic Disturbance, Earthquake, Tornado, Hurricane, Other Catastrophe)
9134	Fuel Conservation