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The Impacts of Climate Change on Concrete Durability - Assessing the Future through Durability Modeling

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Content

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- Service Life
- Climate Change
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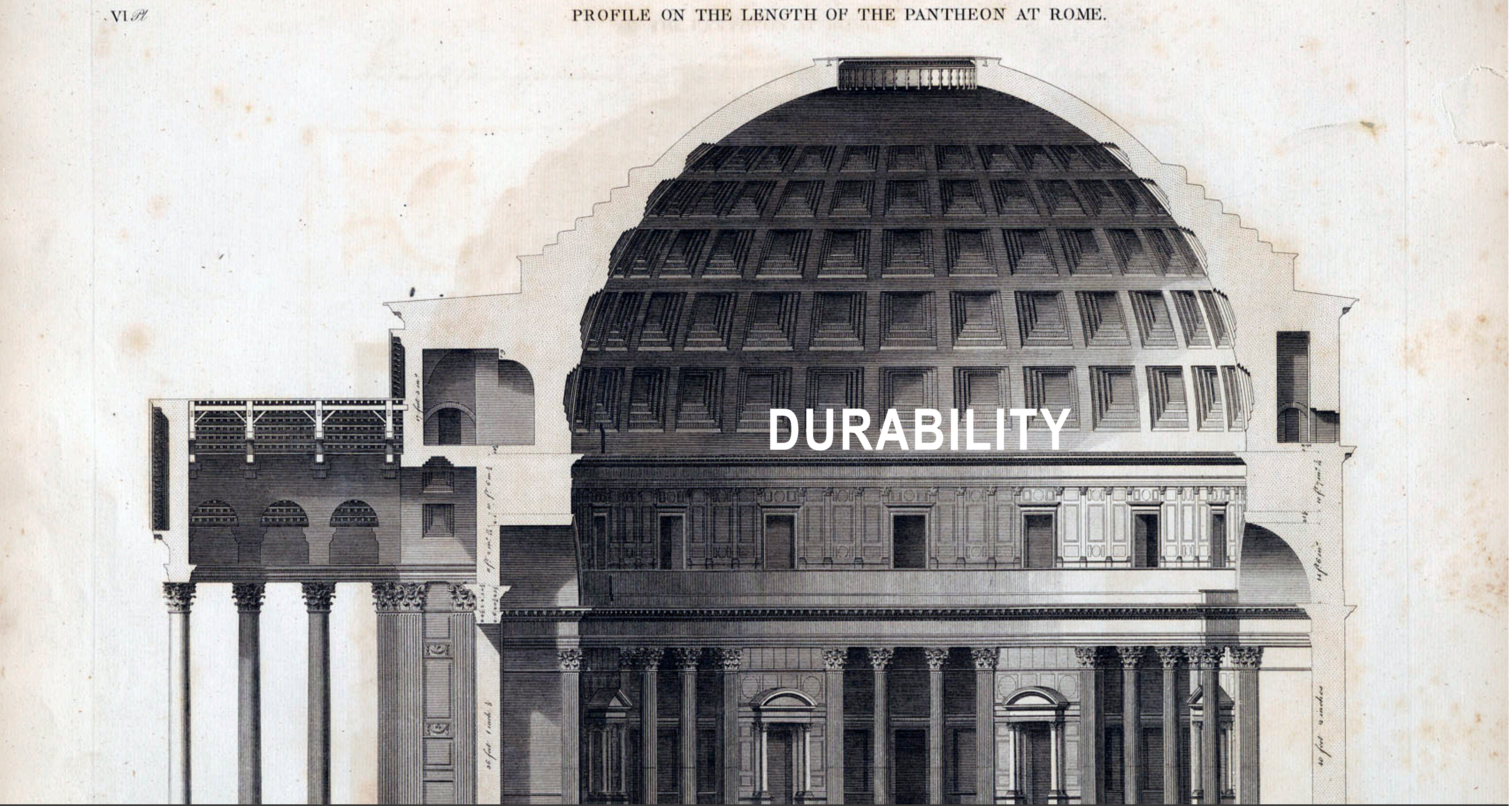
    - Temperature
    - Chloride Thresholds
    - Water
- Considerations/Summary



DURABILITY

It is defined as the ability of concrete to resist weathering action, chemical attack, and abrasion while maintaining its desired engineering properties for the expected service life of the structure. Portland Cement Association

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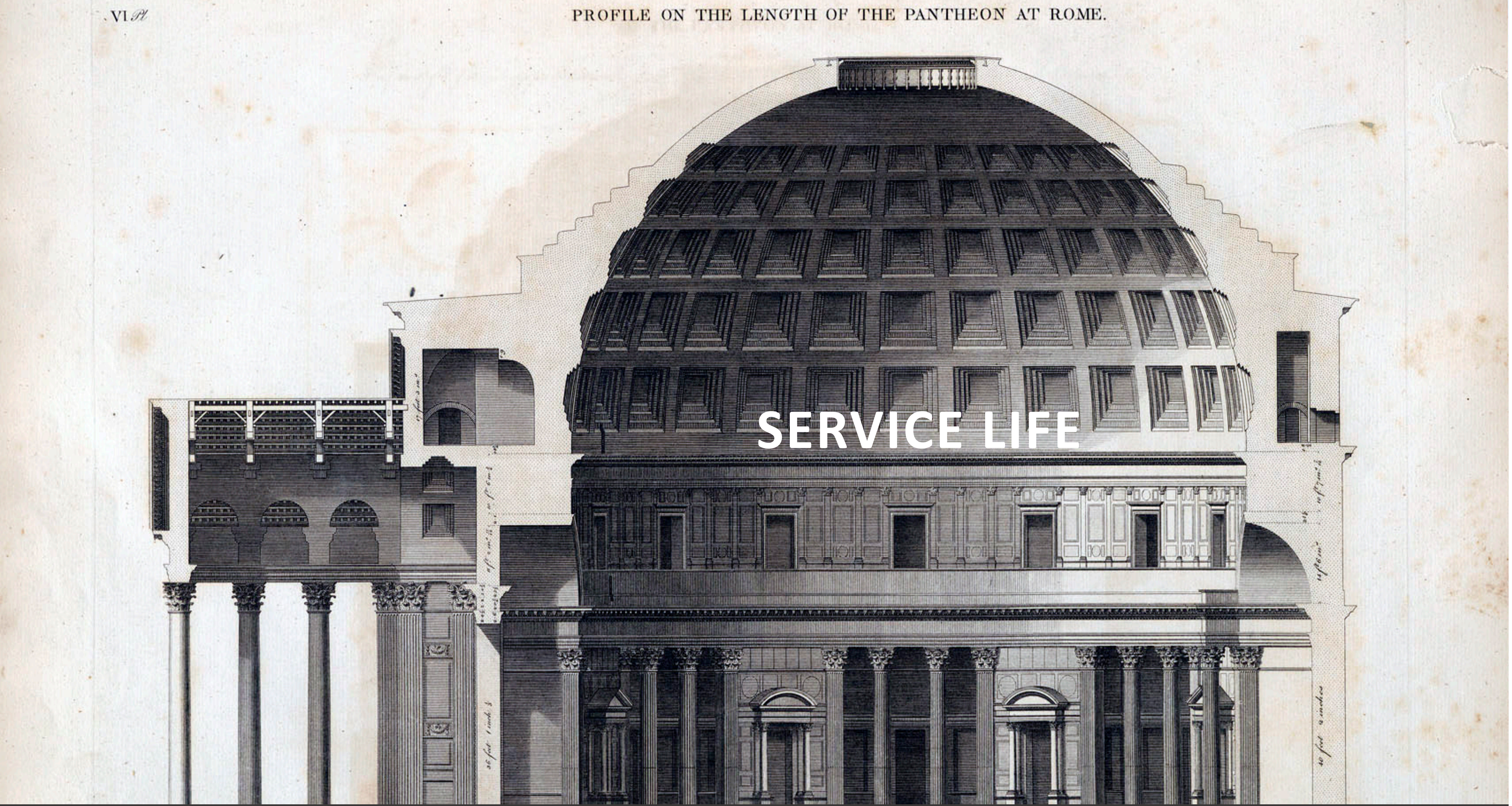

SERVICE LIFE

Service life is the actual period of time during which a structure performs its design function without unforeseen costs for maintenance and repair.

Climate Change

1. Global Temperature Rise
2. Warming Ocean
3. Shrinking Ice Sheets
4. Glacial Retreat
5. Decreased Snow Cover
6. Sea Level Rise
7. Declining Arctic Sea Ice
8. Extreme Events
9. Ocean Acidification

Ref: https://climate.nasa.gov/causes/

https://climate.nasa.gov/earth-now/#/vitalsign?vitalsign=air_temperature&altid=0&animating=f&start=&end=

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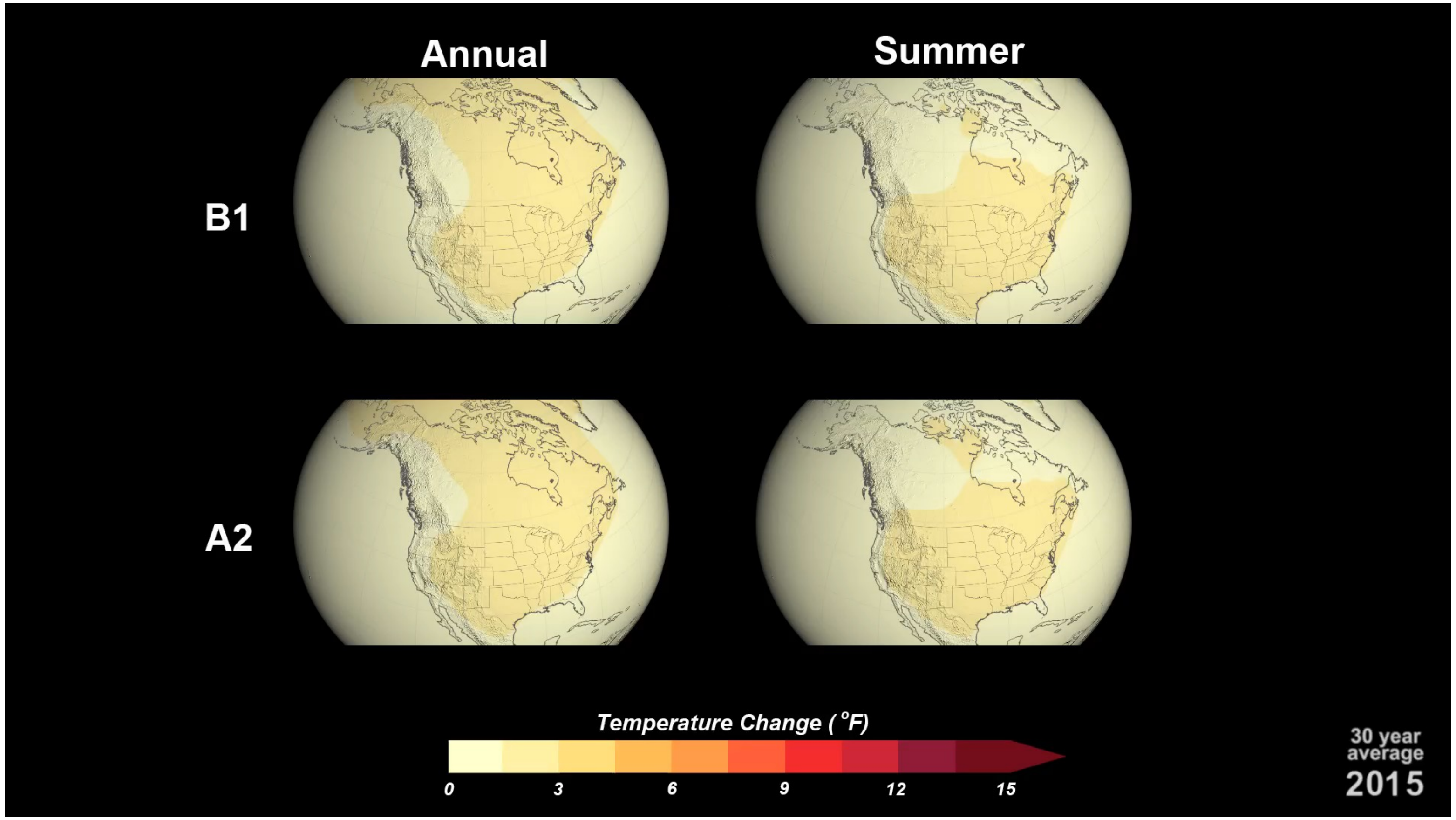
Climate Change

These climate model runs use assumptions about possible future development patterns and greenhouse gas emission rates. Two future scenarios are shown: **B1** and **A2**.

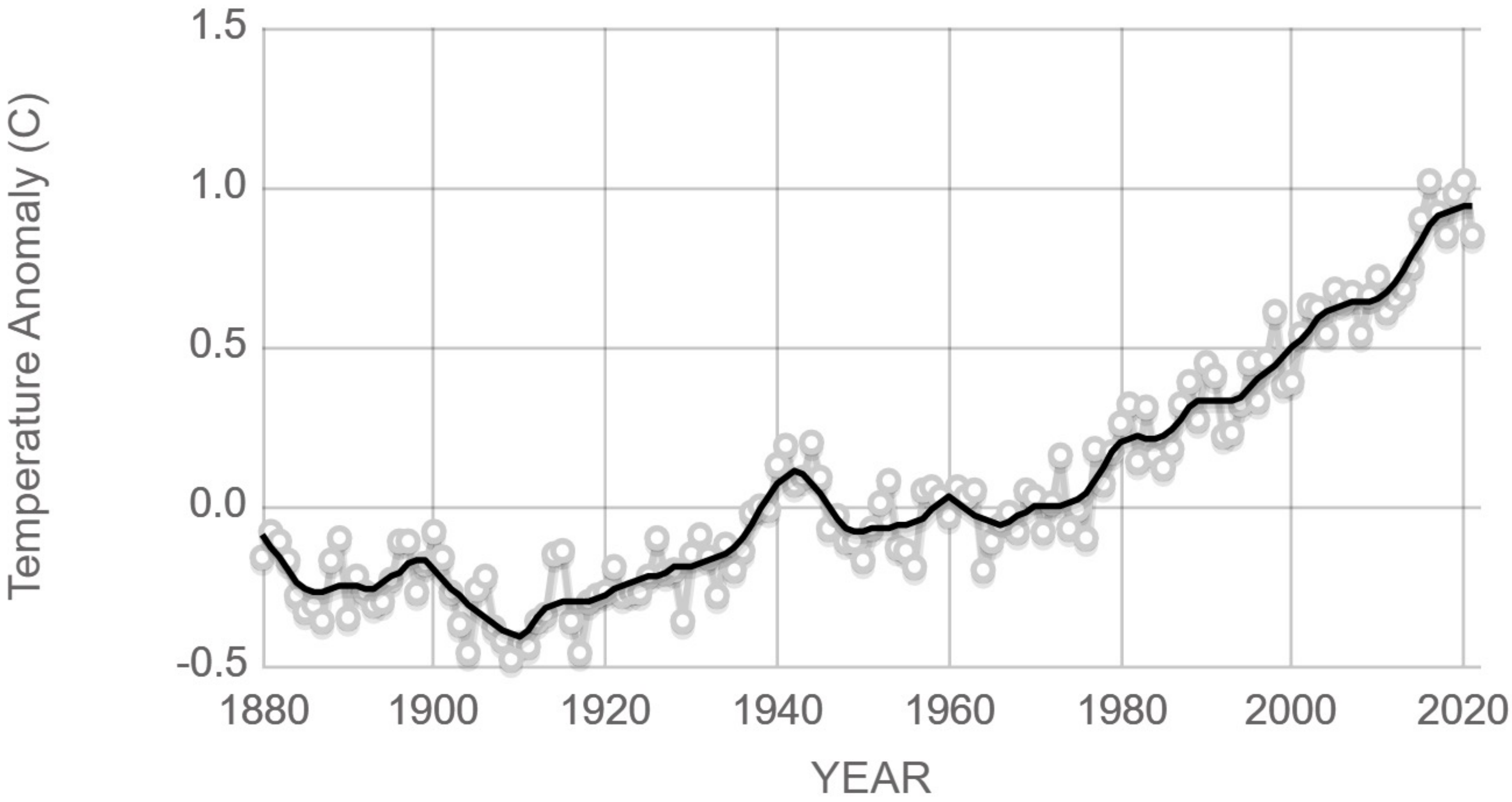
- In the **B1** scenario, global environmental concerns are emphasized. **B1** is a lower greenhouse gas emissions scenario.
- In the **A2** scenarios, future socio-economic development and regional issues are emphasized; and, worldwide cooperation on environmental issues is deemphasized. **A2** is a higher greenhouse gas emissions scenario.

For each scenario (**B1** and **A2**), five individual temperature anomaly animations are shown for annual, summer, fall, winter, and spring periods. So, there are a total of ten individual animations:



Global Temperature Rise

Ref: https://climate.nasa.gov/causes/

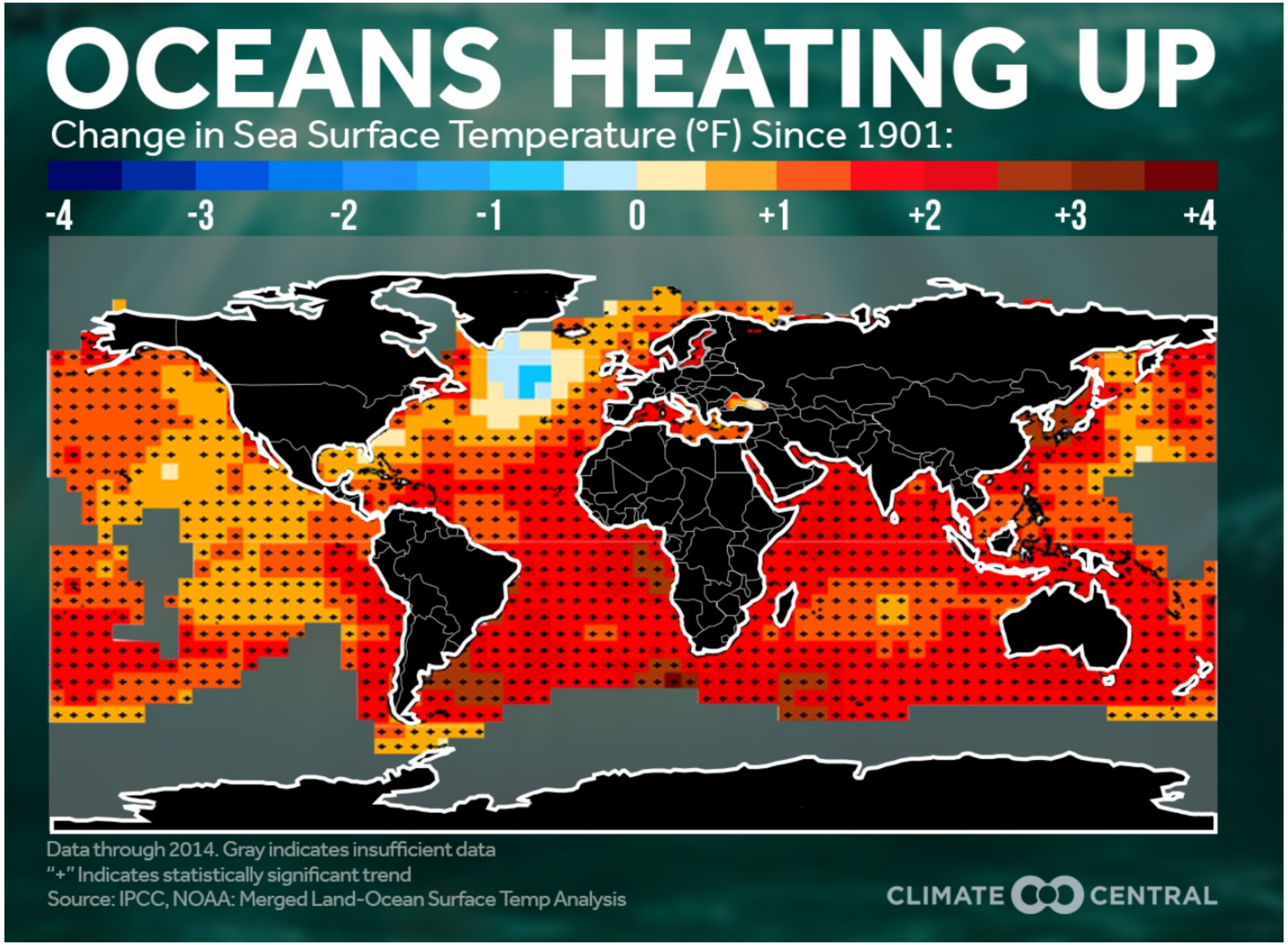


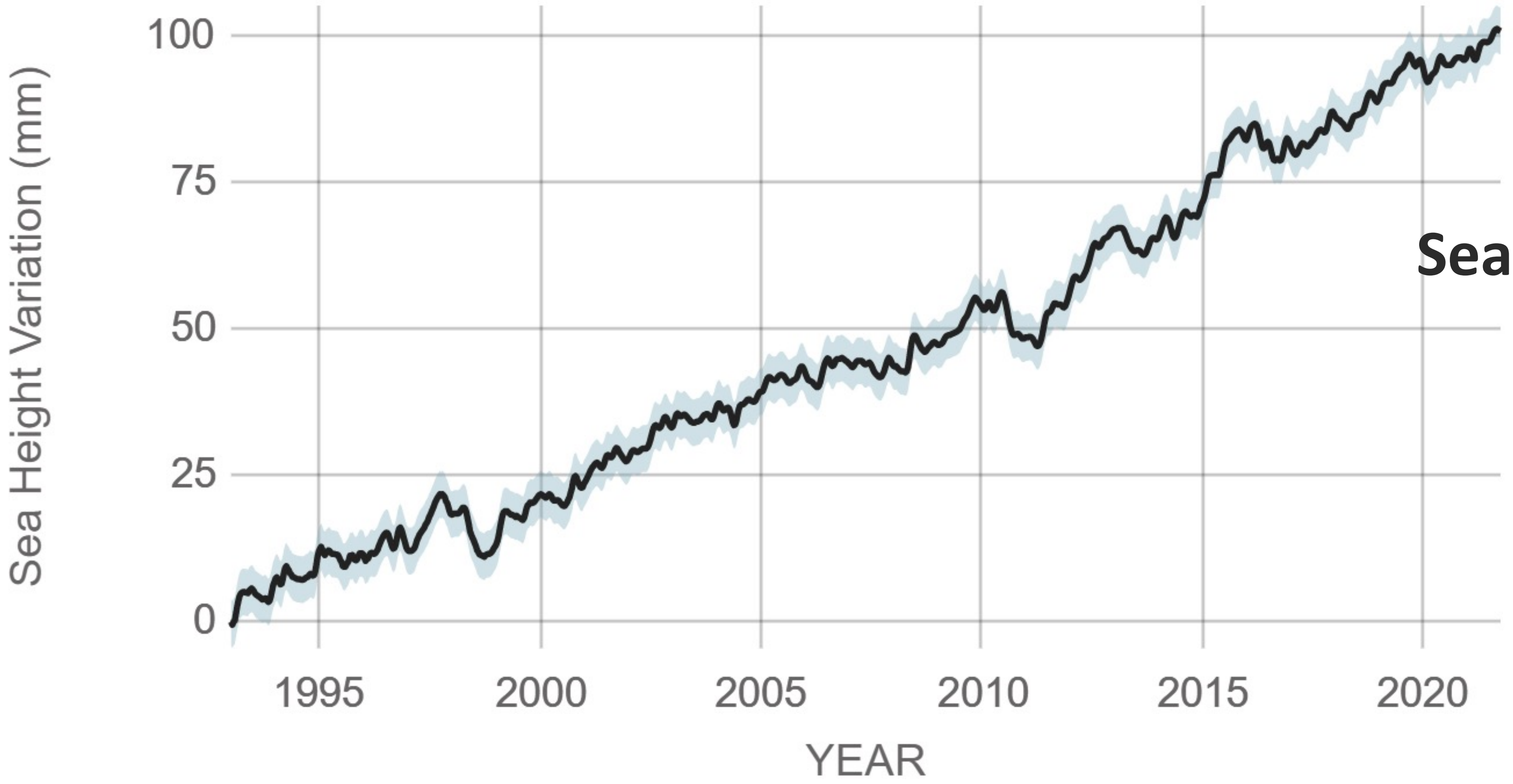
Source: climate.nasa.gov

Global Temperature Rise

Ocean Warming

- Has absorbed much of this increased heat,
- Top 100 meters (about 328 feet) increased >0.6 degrees Fahrenheit since 1969
- Earth stores 90% of the extra energy in the ocean.



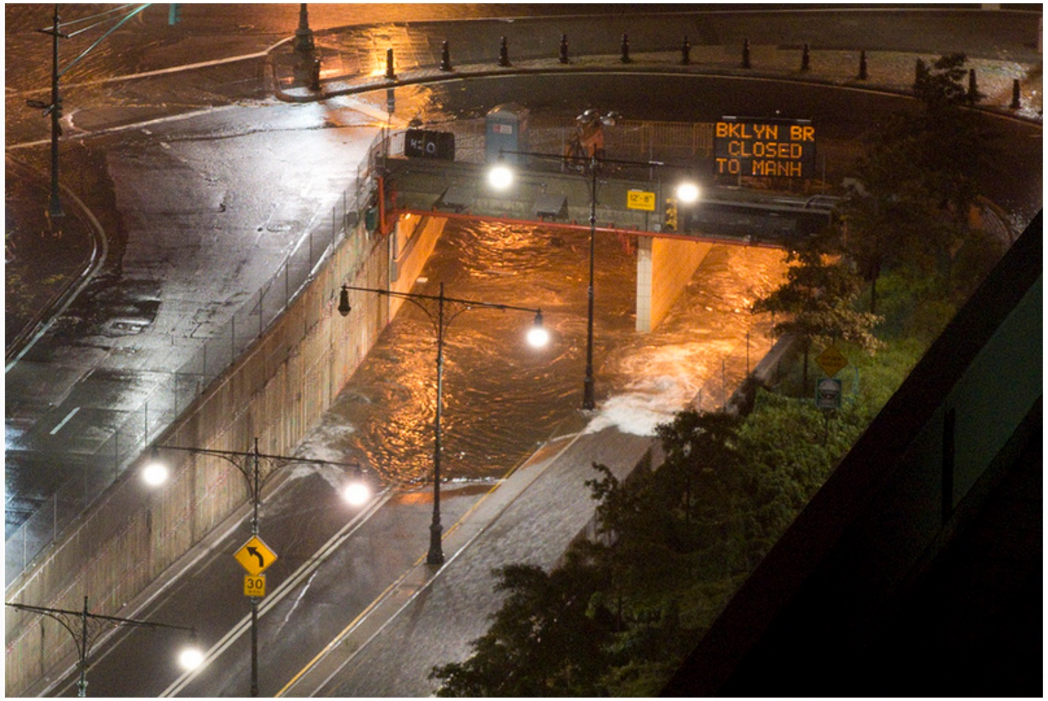


Source: climate.nasa.gov

Sea Level Rise

It is projected to rise another 1 to 8 feet by 2100

Extreme Events - Flooding

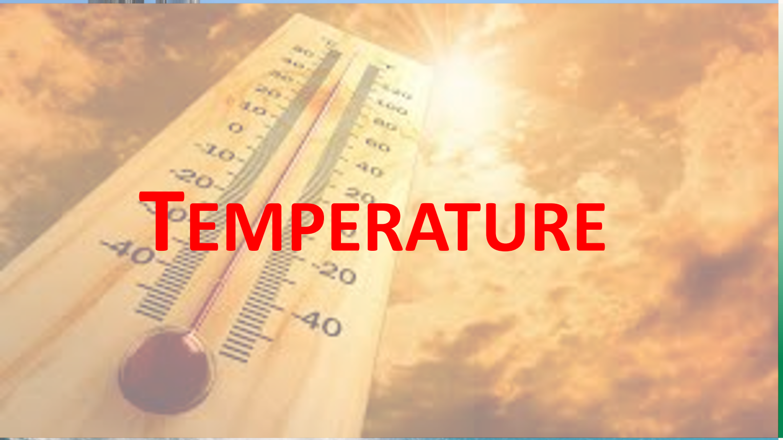


Sandy West St underpass flooding. Photo courtesy of Jay Fine for the ***MTA*** *via Flickr Creative Commons*

Effects of Climate Change on Reinforced Concrete

❑ CO_2 Emissions

- Increase in CO_2 levels in the last decades



❑ Temperature

- Rise in Temperature
- High Humidity levels

❑ Rising Water Level

- Rising Water Table
- Frequent flooding/High tides
- Time of WETNESS [TOW]
- Increased Salt Loads, Ground Salinity

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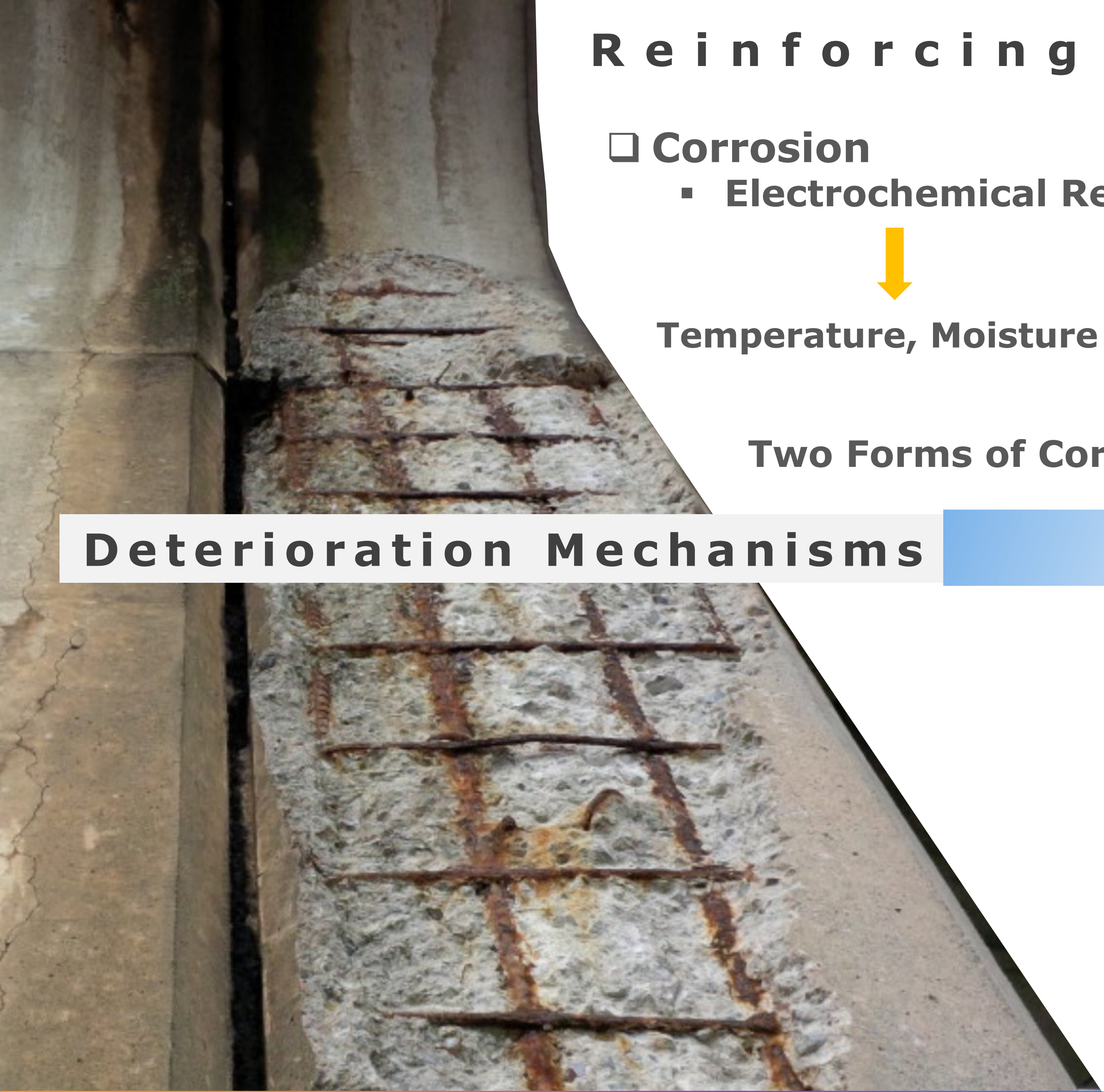


Reinforcing Steel in Concrete

- Corrosion
  - Electrochemical Reaction

↓

Temperature, Moisture & Oxygen

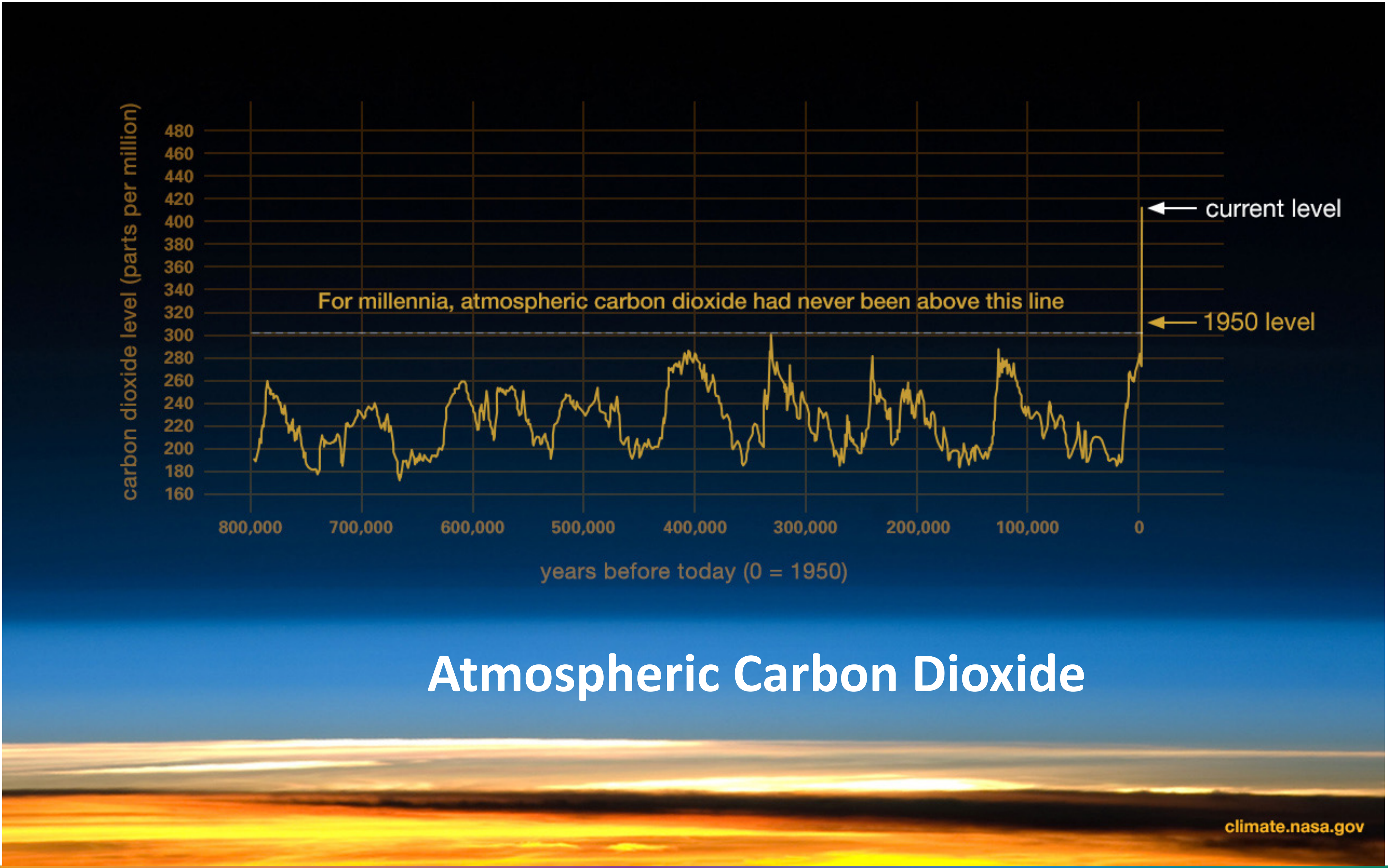
Two Forms of Corrosion → Carbonation

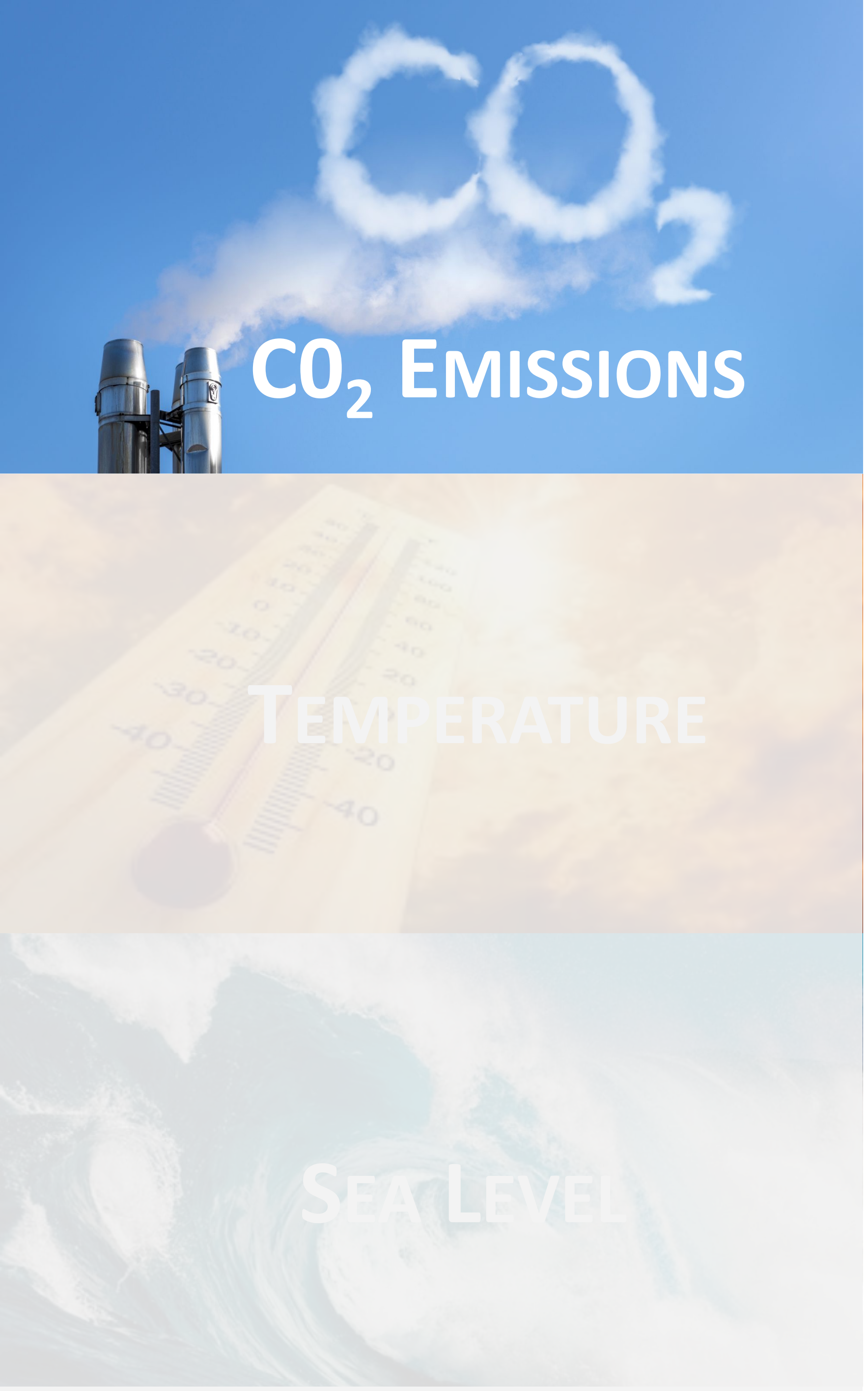
→ Chloride [Pitting]

Deterioration Mechanisms

Environment

Effects of Climate Change on Concrete

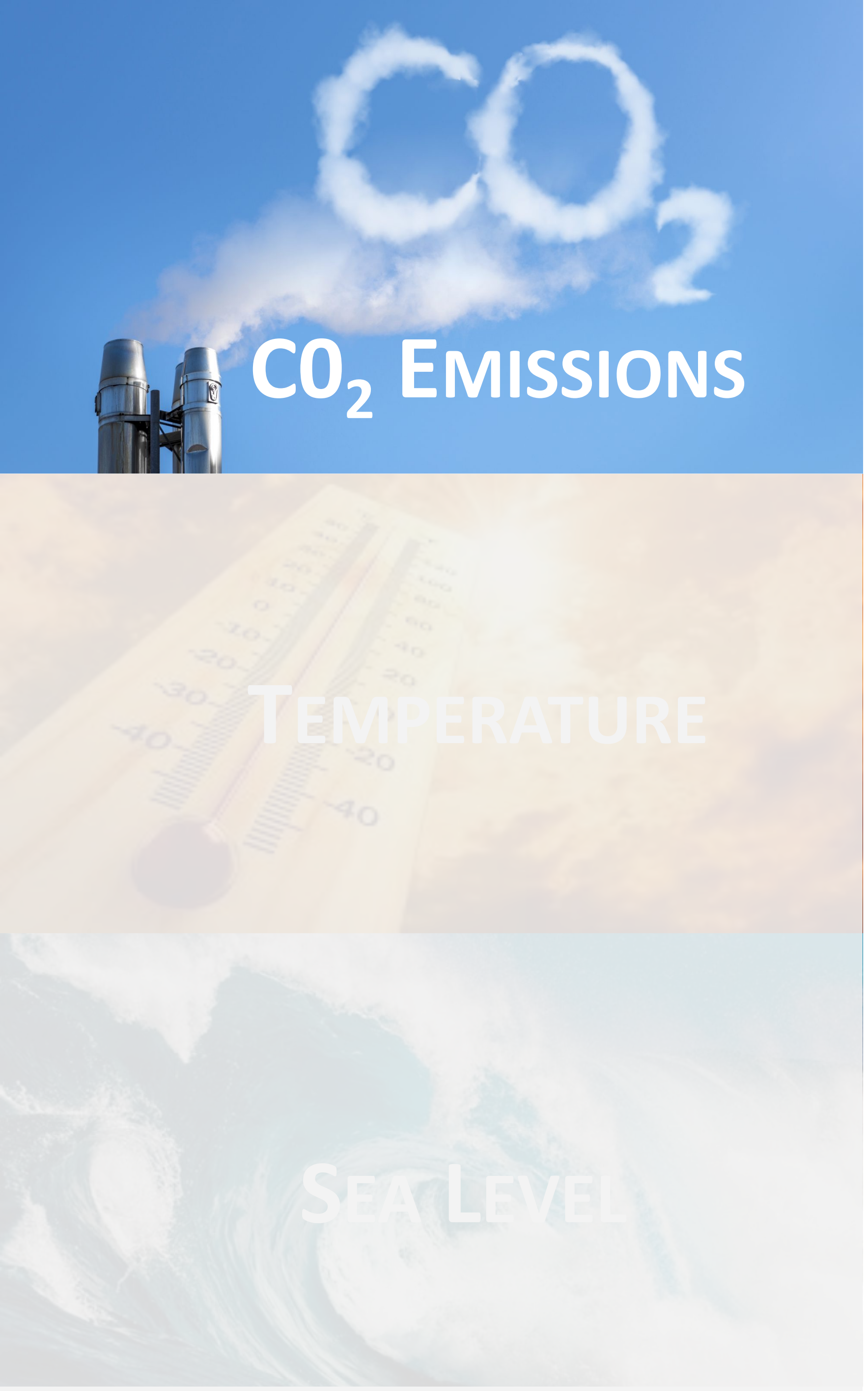


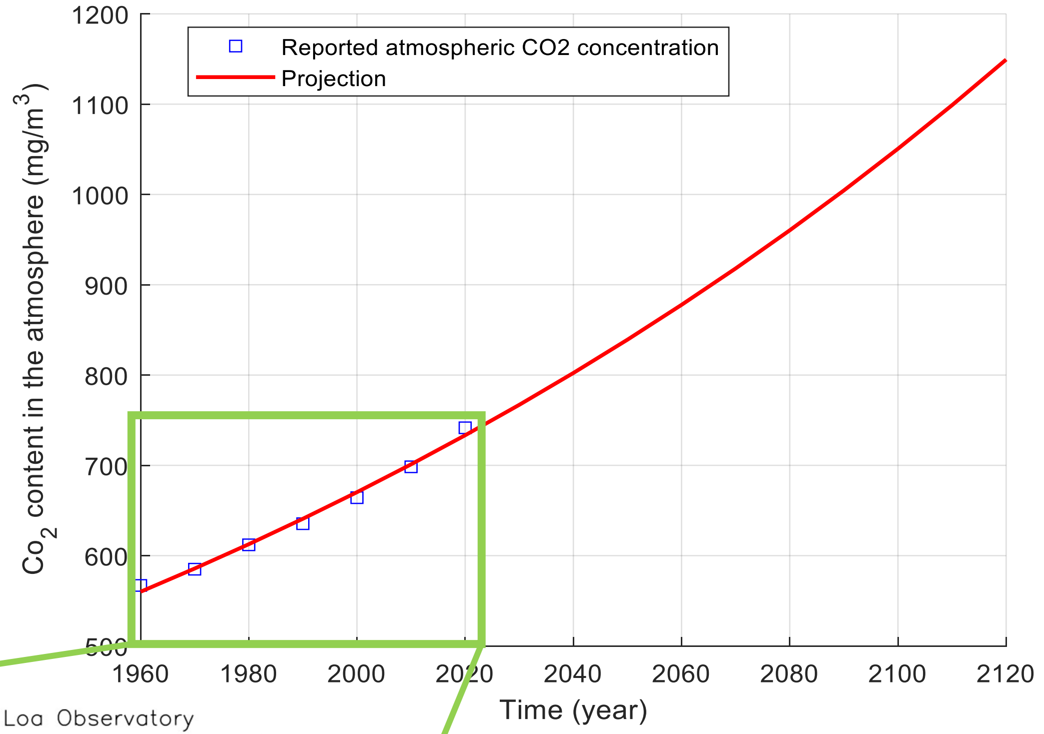


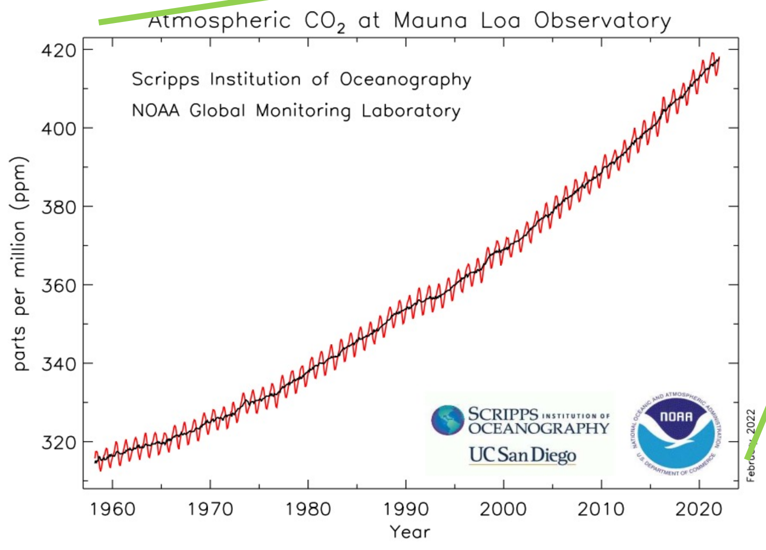
Effects of Increased Carbonation on Concrete

- Carbonation depth is more or less a power function of the CO_2 concentration in the form of $y = a(x)\ n$
- Assume $n = 0.5$, carbonation depth can be taken as a square root function of the CO_2 concentration.
- Then, a 10% increase in CO_2 concentration would lead to a 5% increase in carbonation depth.

Effects of Increased Carbonation on Concrete



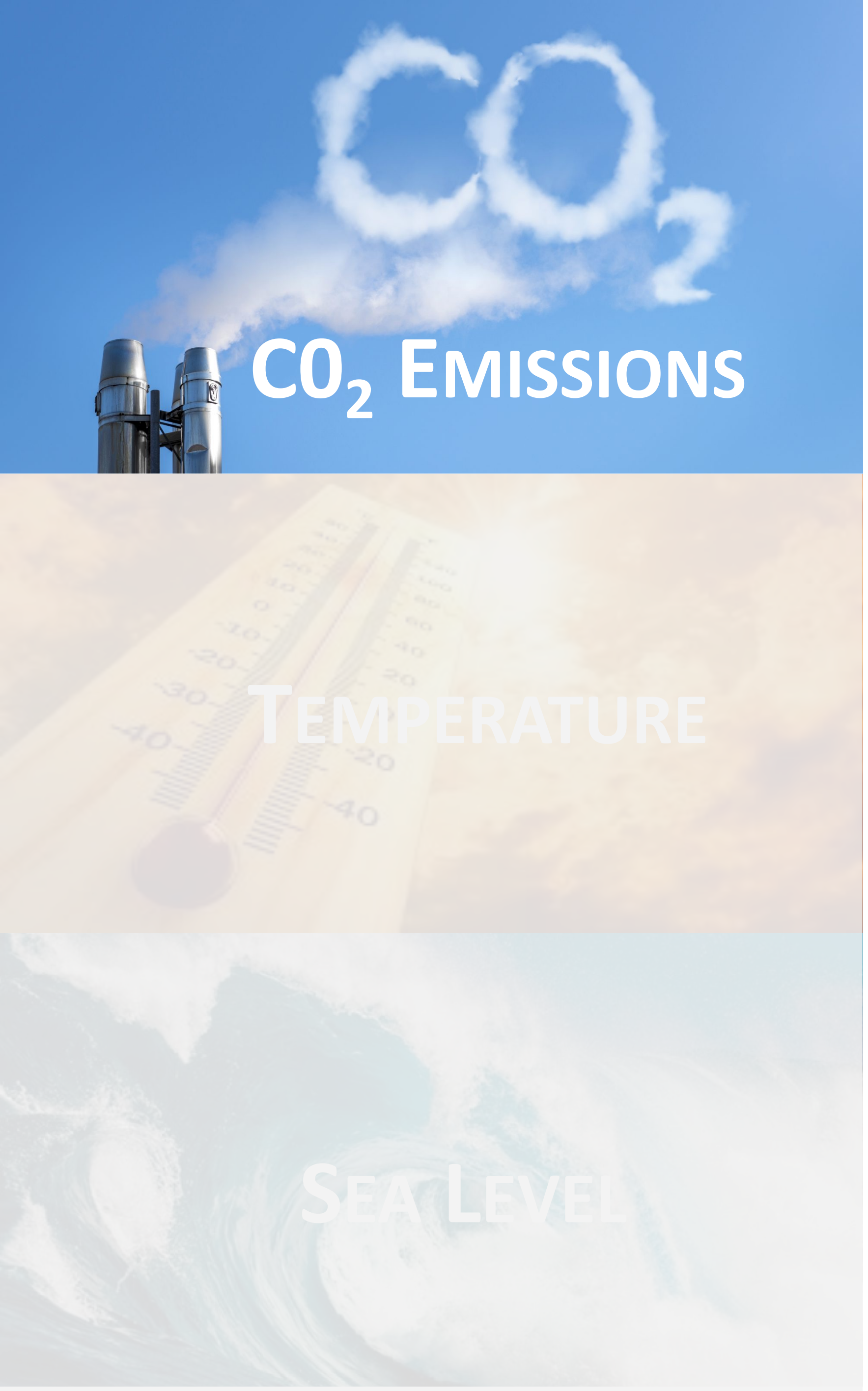


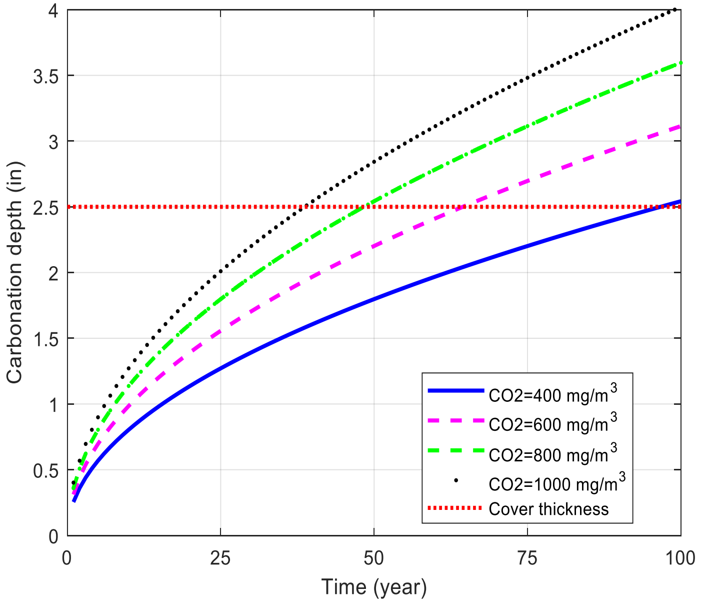


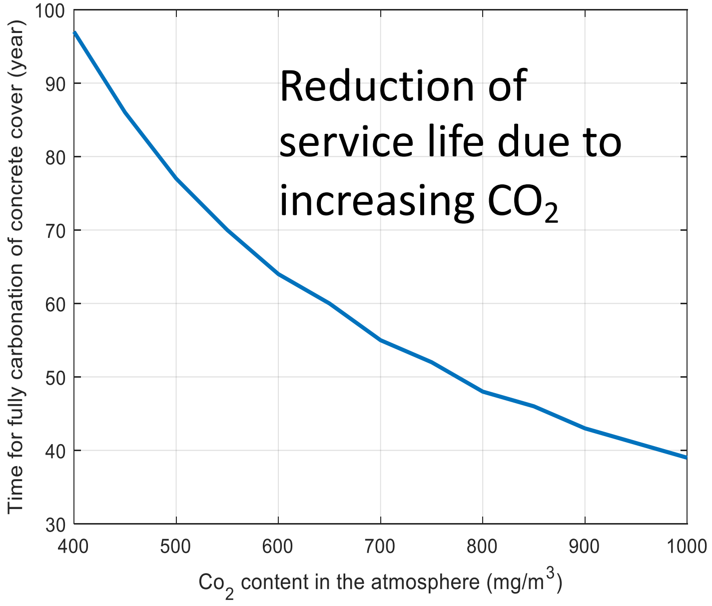
0.0409 x concentration (ppm) x molecular weight (44.01 g/mol)

Ref: Global Monitoring Laboratory - Carbon Cycle Greenhouse Gases (noaa.gov)

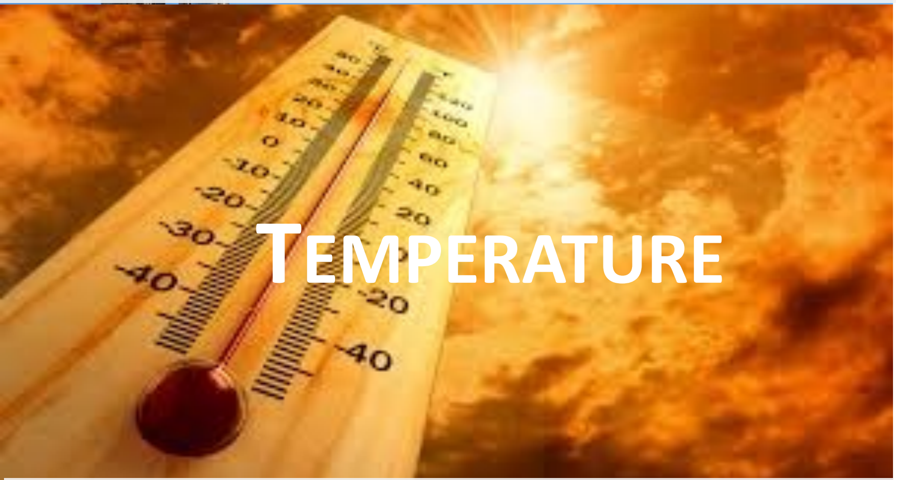
Effects of Increased Carbonation on Concrete

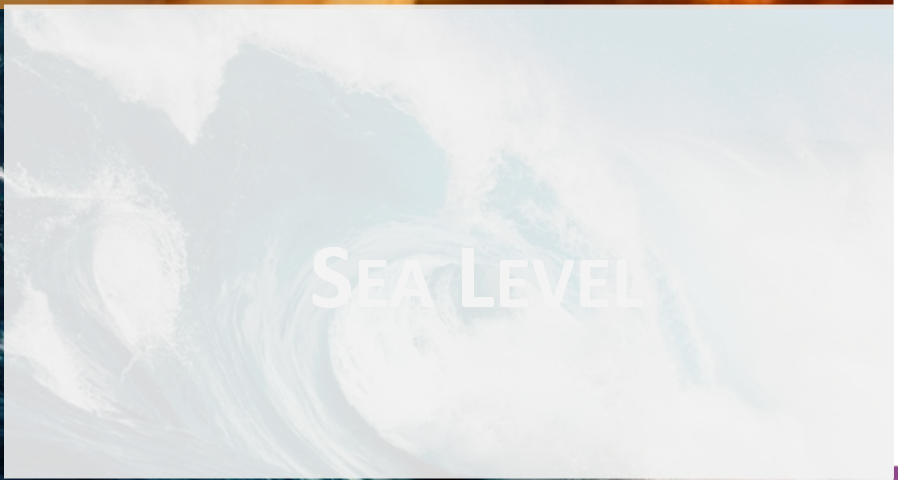




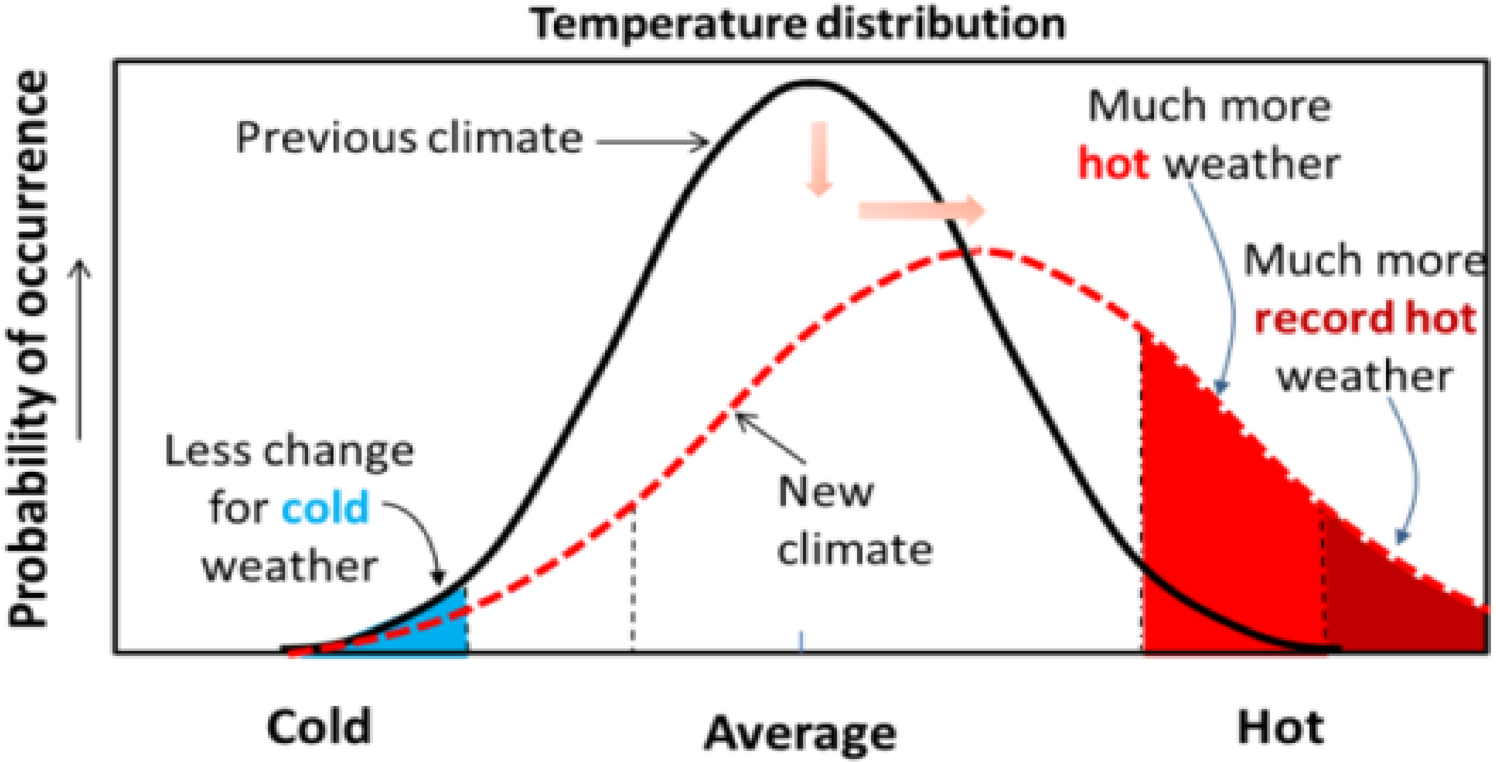



```
C_co2=400-1000 mg/m3 CO2 in the ambient atmosphere
T=16;% Temperature in C
RH=55;% RH in %
w/c=0.5;% water to cement ratio;
```





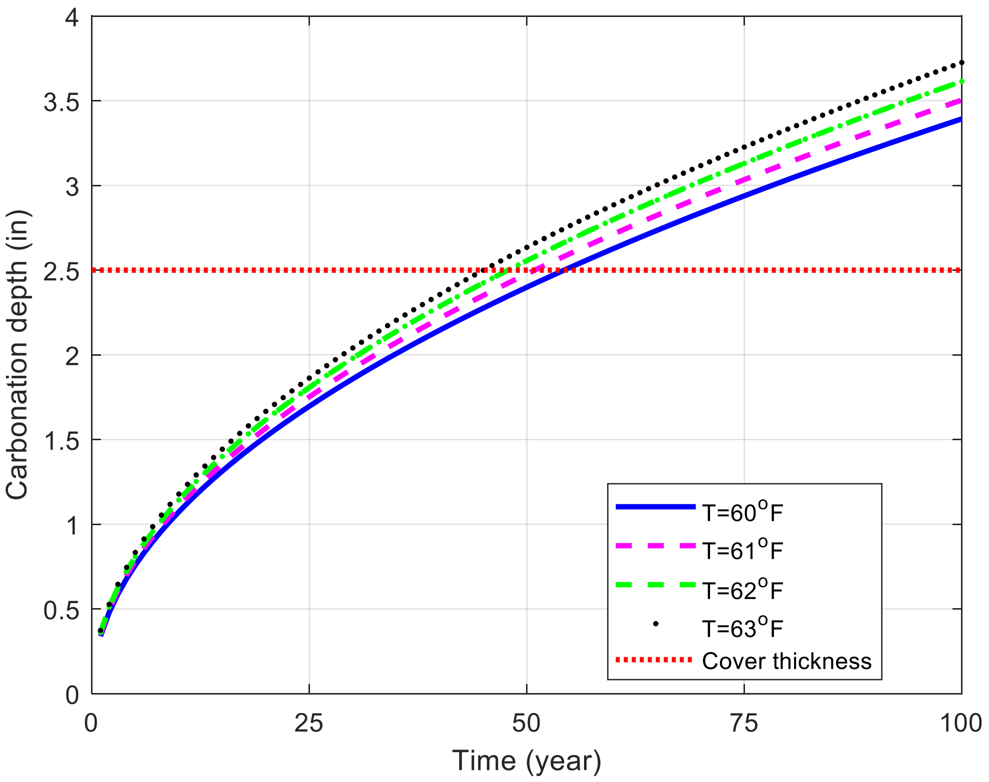
Effects of Increased Temperature on Concrete

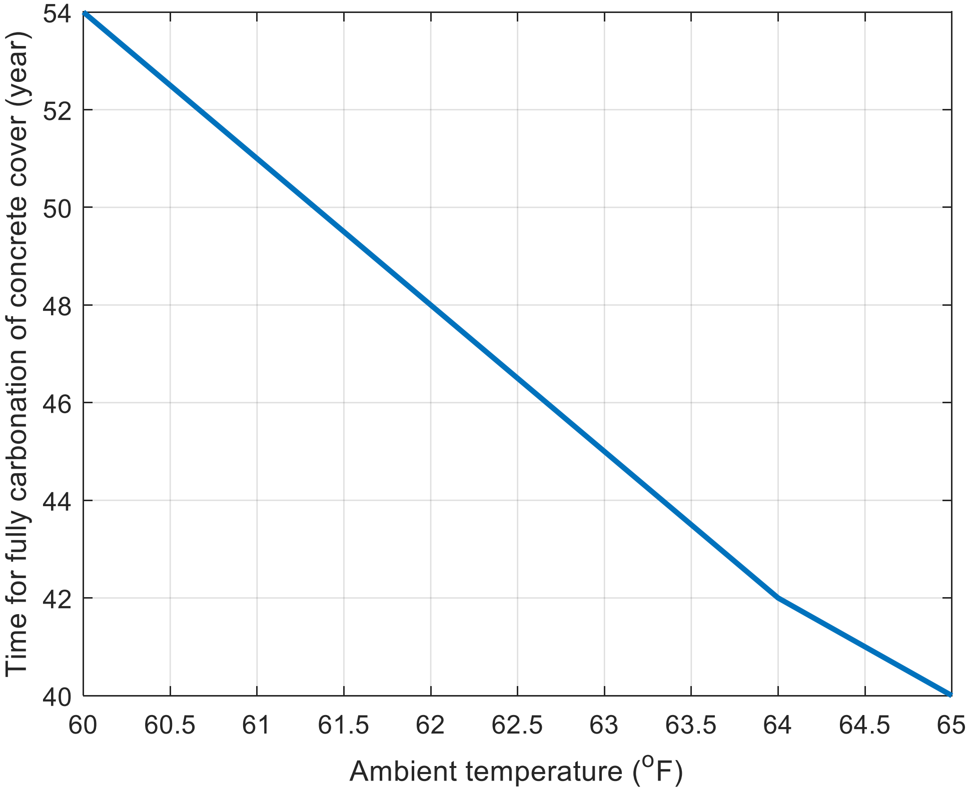


Effects of Increased Temperature on Concrete

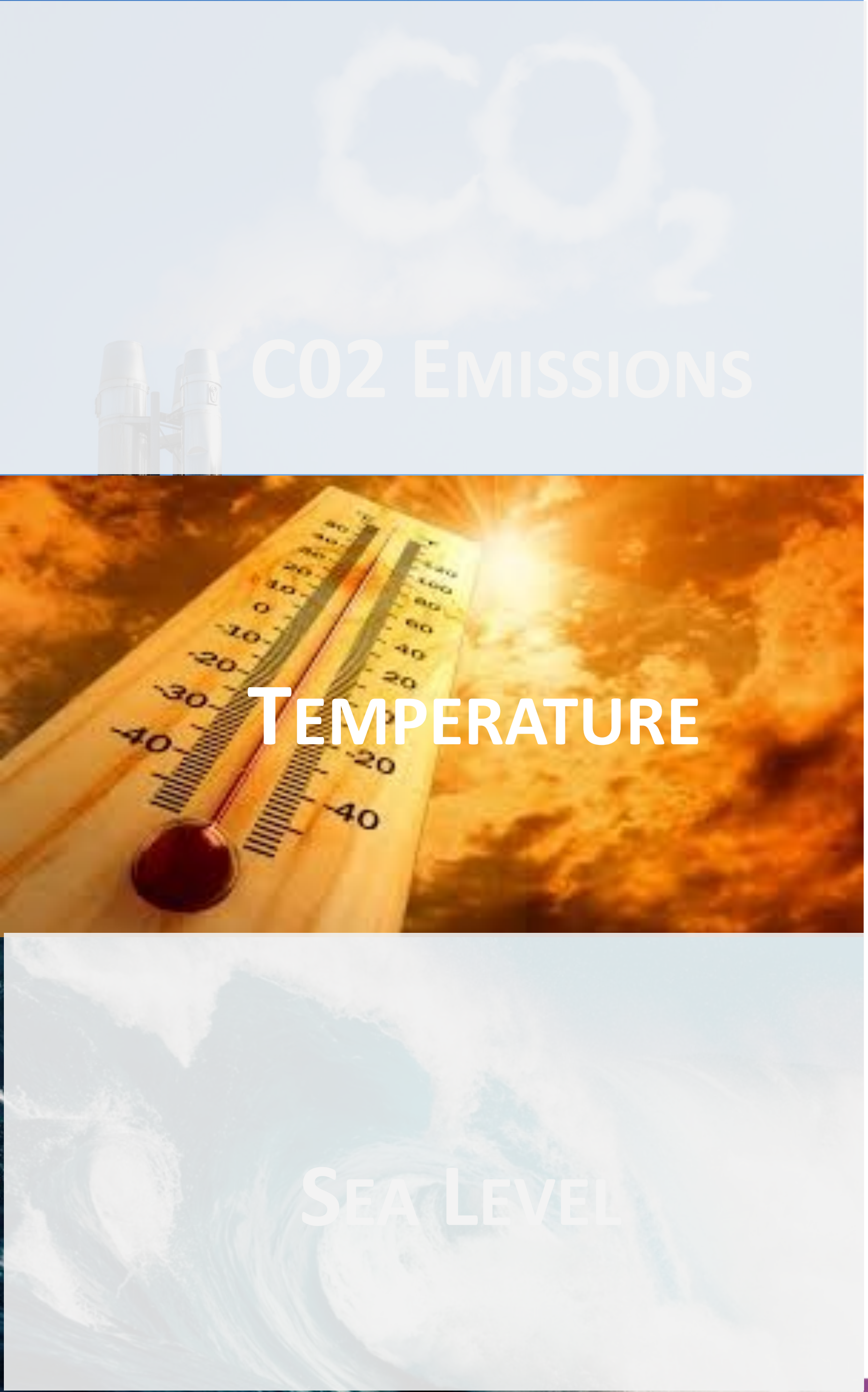
- Carbonation Depth and Temperature increment in US = 0.16 °F /decade. [1]

```
C_co2=750 mg/m3 ;% mg/m3 CO2 in the ambient atmosphere
R=1;% No finishing on surface
Tf=60:1:64;% Temperature in F
RH=55;% RH in %
w/c=0.5;% water to cement ratio;
```





[1] Climate change and the 1991-2020 U.S. Climate Normals | NOAA Climate.gov



Effects of Increased Temperature on Concrete

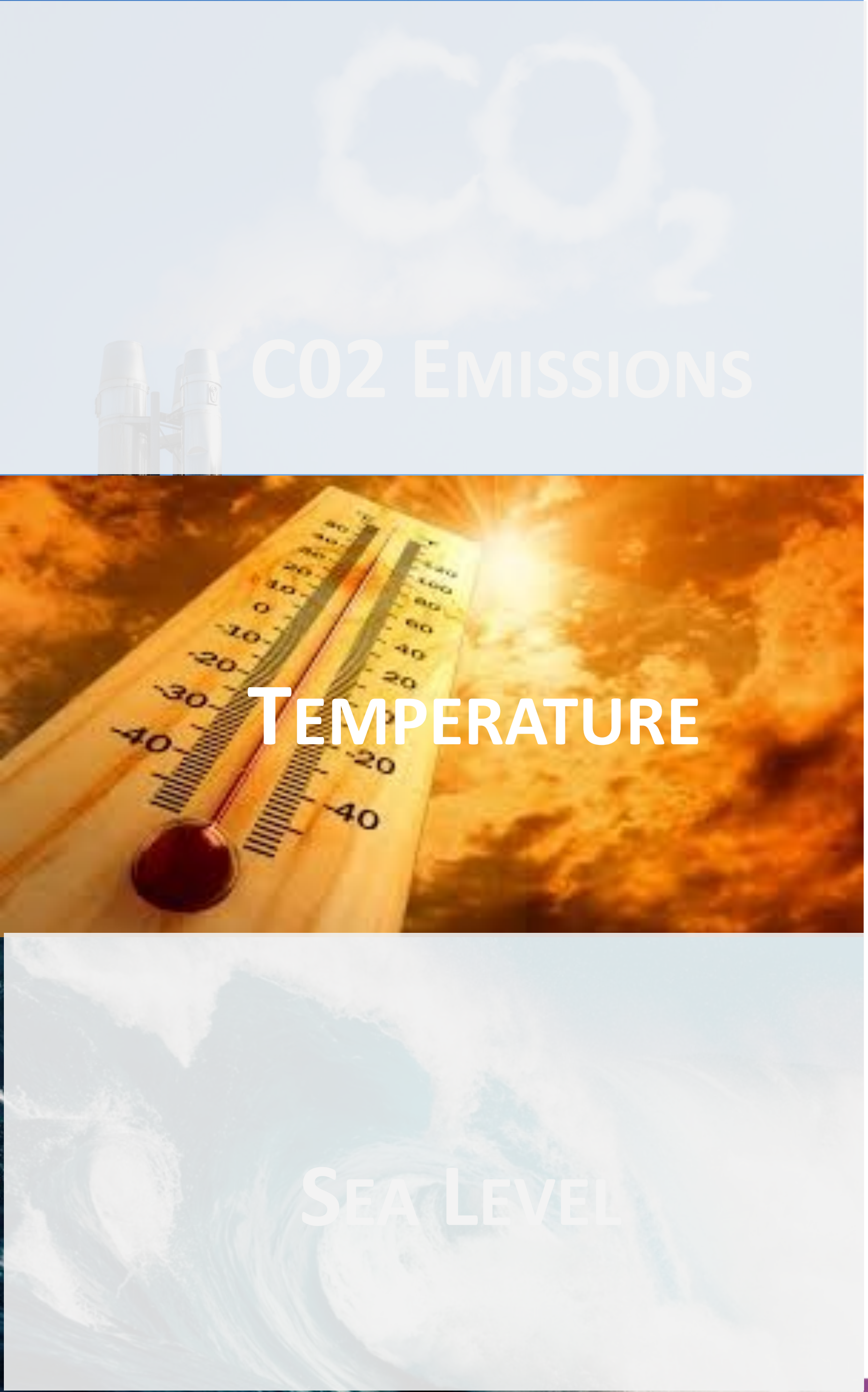
Chloride diffusion rate and oxygen diffusion rates

Arrhenius equation

$$k = Ae^{\frac{-E_a}{RT}}$$

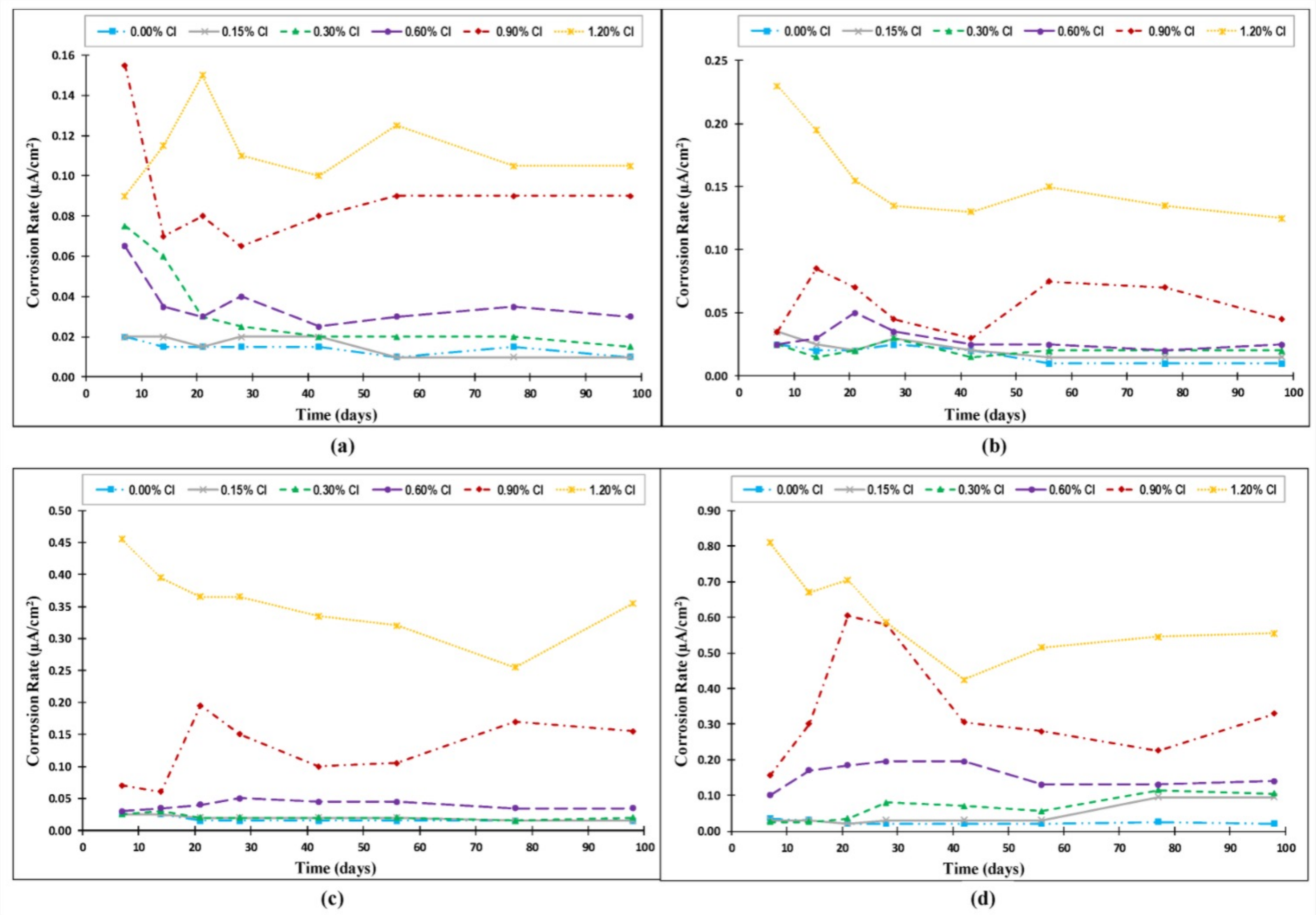
10°C increase = 100% increases in diffusion

At 4°C rise, provides 40% increases in diffusion

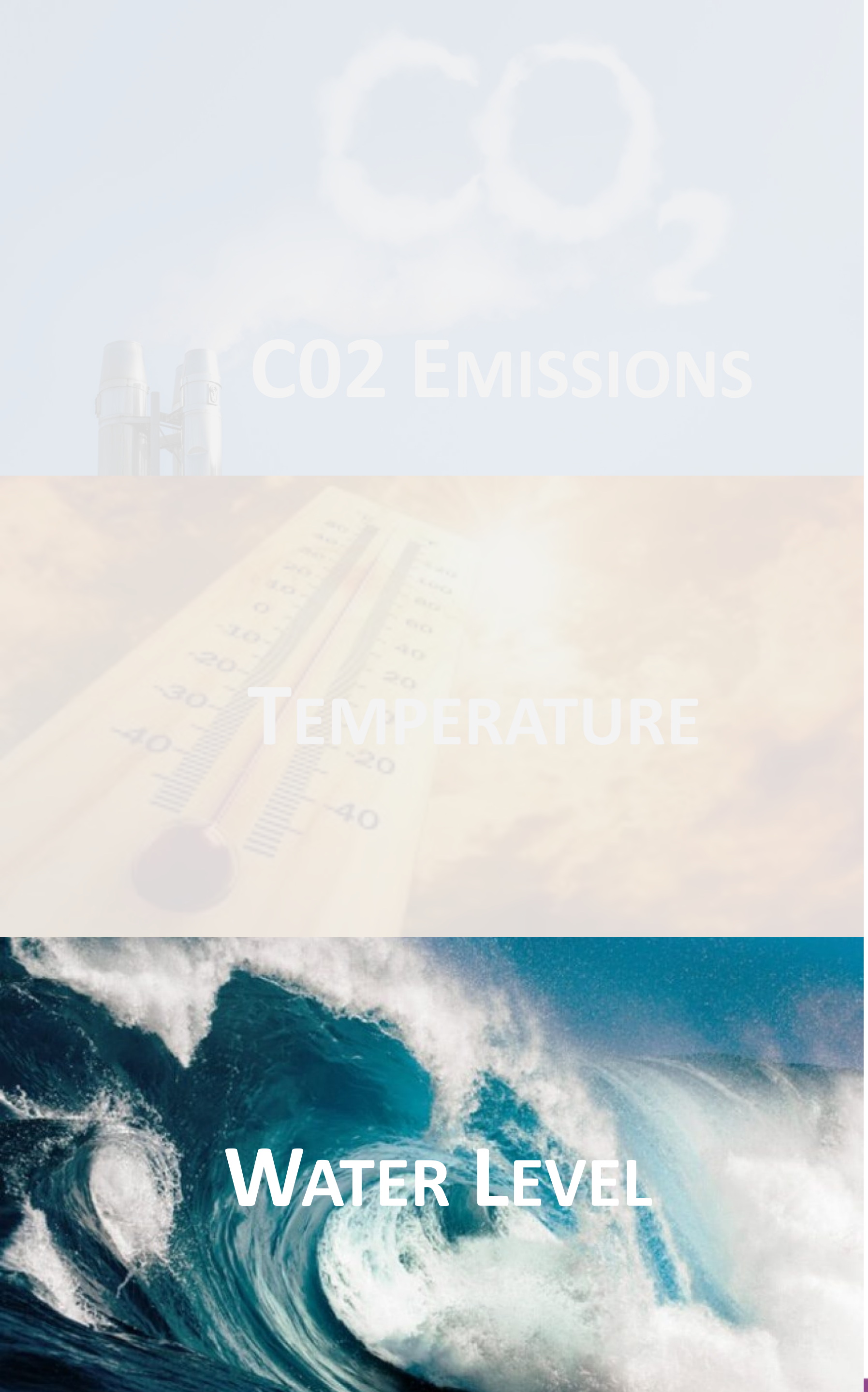


Effects of Increased Temperature on Concrete

(**a**) 20 °C (68 °F), (**b**) 35 °C (95 °F), (**c**) 50 °C (122 °F), and (**d**) 65 °C (149 °F) (Source A).

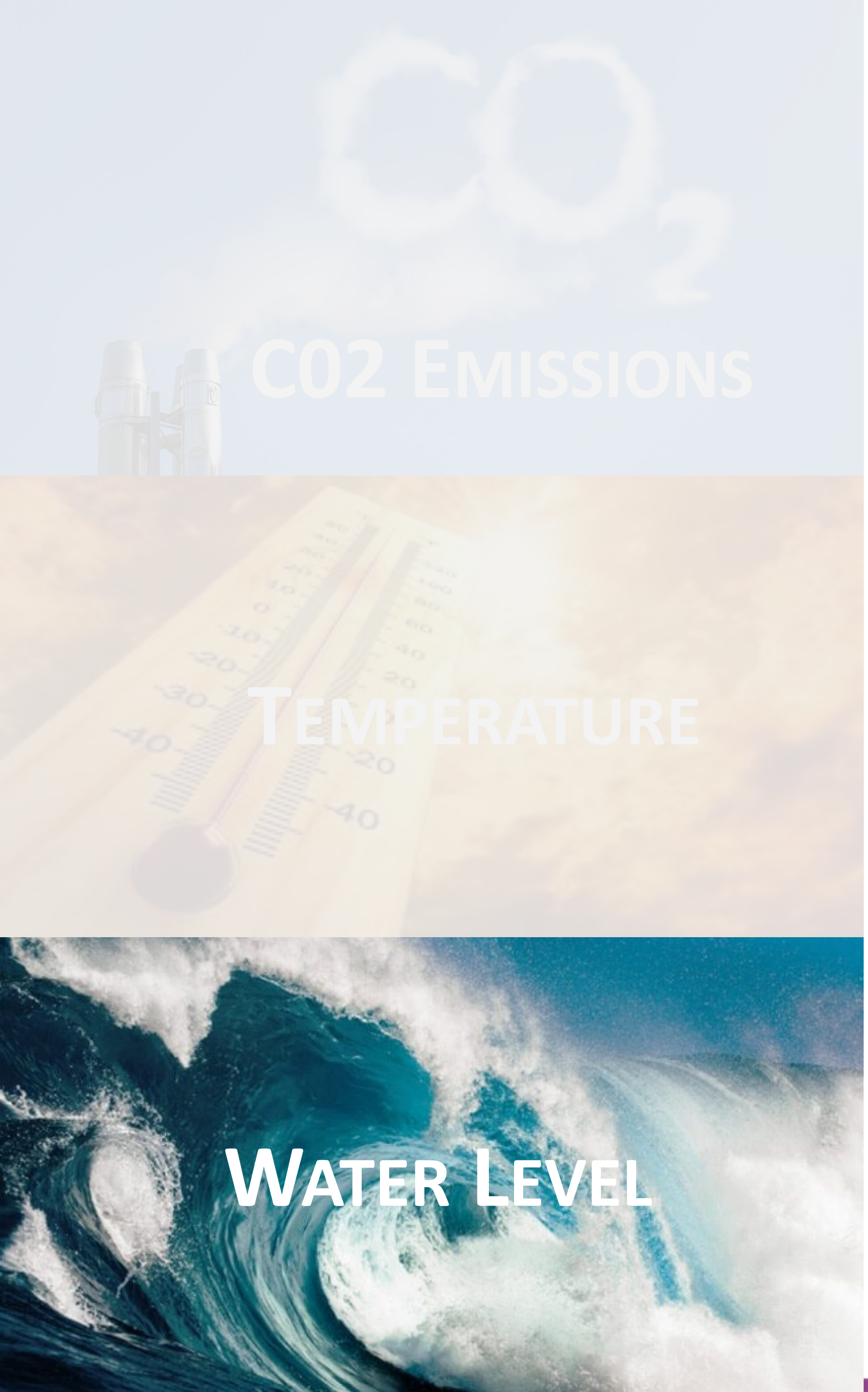


Corrosion Rates and Chloride Thresholds



Effects of Water Changes on Concrete

- Frequent Flooding
- Higher tides
- Increase in height of Water Table
- Flooding Increasing contaminants
- Increase numbers of Wet/Dry Cycle and time of wetness

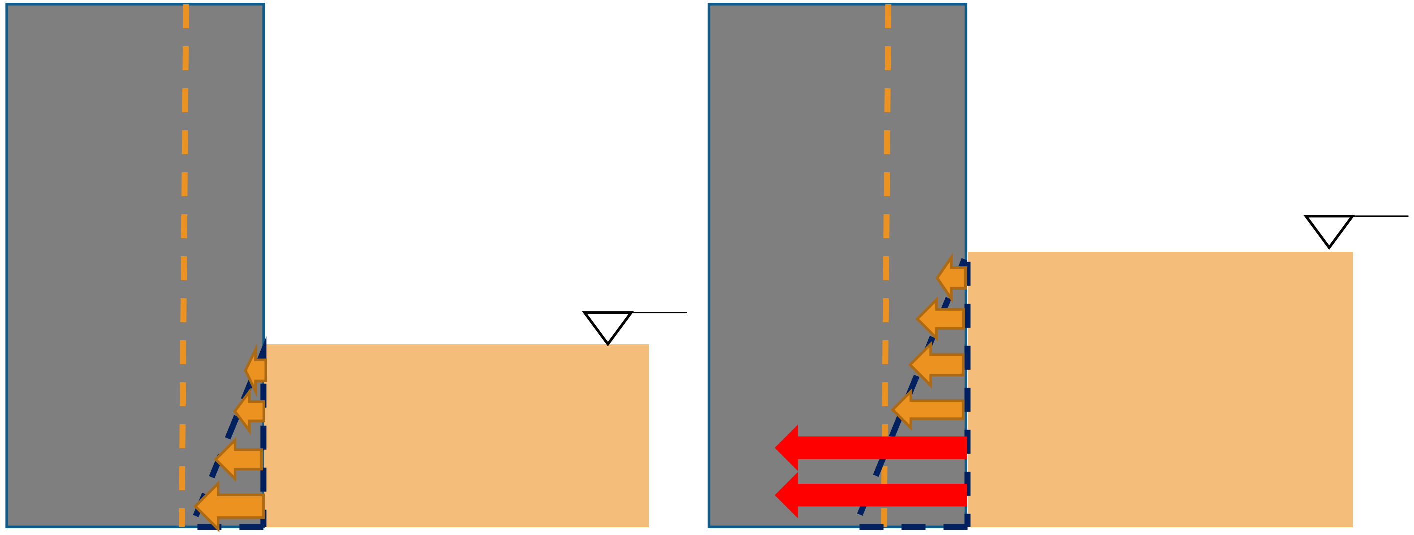


Effects of Water Changes on Concrete

- Frequent Flooding
- Higher tides
- Increase in height of Water Table (Hydraulic Pressure)
- Flooding Increasing contaminants
- Increase numbers of Wet/Dry Cycle and time of wetness
- Ground salinity in coastal areas increases
- Rising tides impact building foundation performance

Effects of Water Changes on Concrete

- Head Pressure increases – beyond the thresholds, the hydraulic pressure will be the driving force of chloride ingress (instead diffusion)



chloride ingress (diffusion)

chloride ingress (hydraulic pressure)

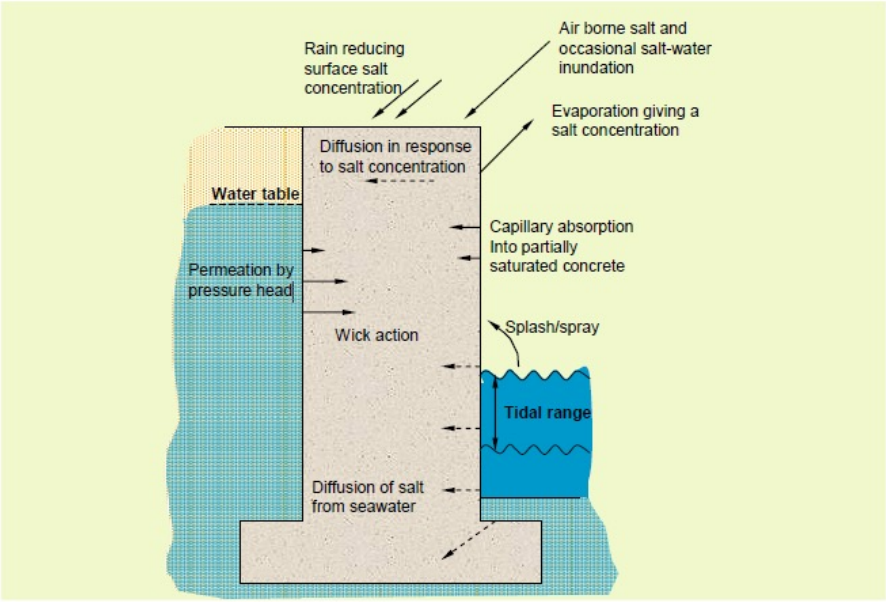


Figure 3-3 Chloride transport process in a maritime structure described by BS 6349-1

Source: BS (2000)

Effects of Water Changes on Concrete

By considering hydraulic pressure, chloride model can be modified as following [4]:

$$C_x = (C_0 + (C_{sn} - C_0) \cdot 0.5 \cdot \left[\mathrm{erfc}\left(\frac{x - vt}{2\sqrt{D_{ca}t}}\right) + \exp\left(\frac{vx}{D_{ca}}\right) + \mathrm{erfc}\left(\frac{x + vt}{2\sqrt{D_{ca}t}}\right)\right]$$

$v = -\mathrm{KH}$ = average linear rate of flow; $K = \mathrm{k}\rho g$ permeability coefficient and H = water head (m)

Surface chloride concentration = **2.2%**; uncertainty factor ($\psi \neq 1$)

W/C ratio	Mix	ψ	D_{ca}	Time to corrosion initiation (Year) 45 mm	50 mm	55 mm	60 mm	65 mm	70 mm
0.4	PFA25	0.2477	3.74E-12	48	75	91	108	127	147
0.45	PFA25	0.2503	4.42E-12	40	63	77	91	107	124
0.4	PFA35	0.2477	3.25E-12	52	81	98	117	137	159
0.45	PFA35	0.2503	3.82E-12	44	69	84	99	117	136
0.4	GGBS50	0.2477	3.51E-12	51	80	97	115	135	157
0.45	GGBS50	0.2503	4.14E-12	43	67	82	97	114	133
0.4	GGBS70	0.2477	3.26E-12	52	81	98	117	137	159
0.45	GGBS70	0.2503	3.84E-12	44	69	83	99	116	134

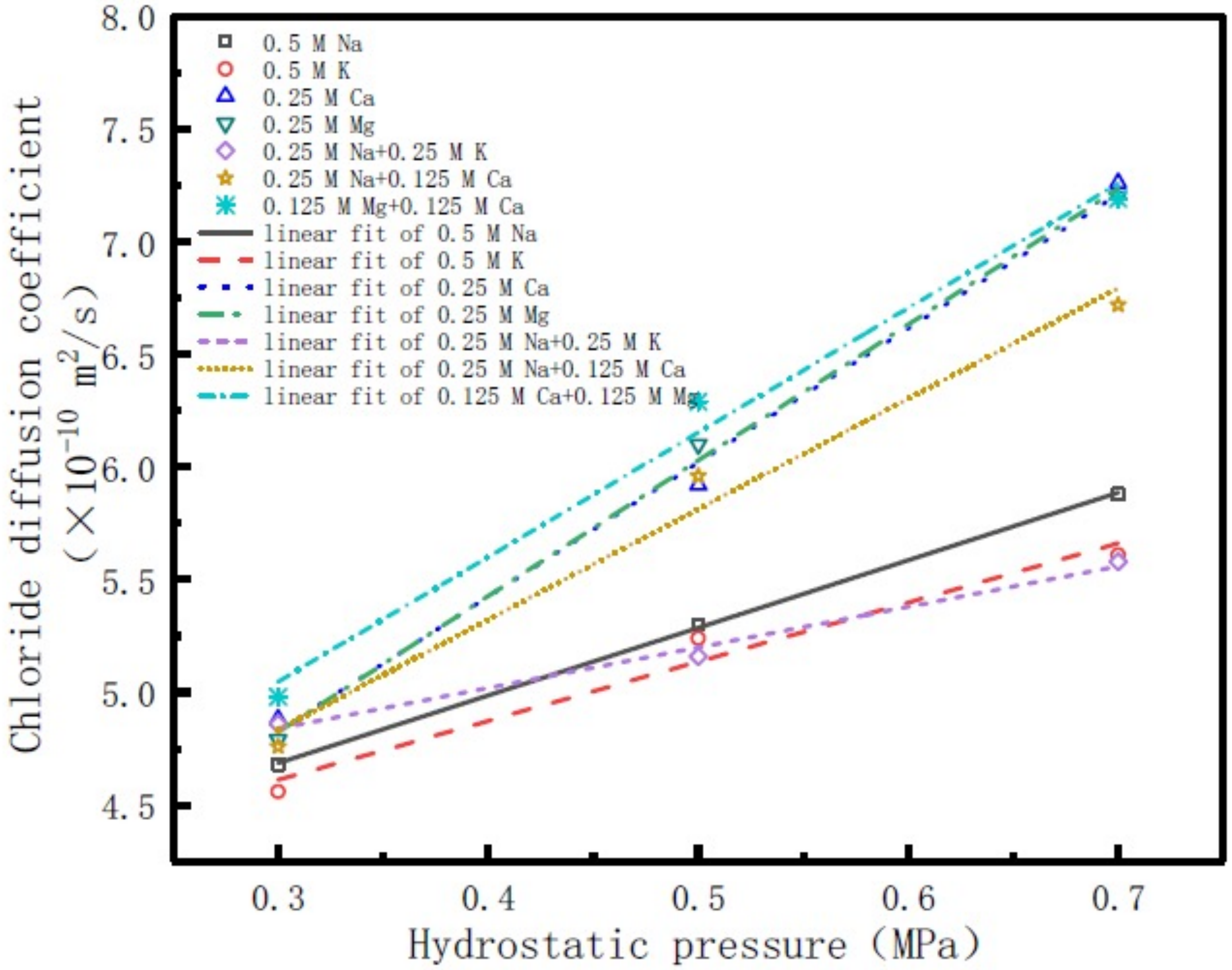
+ hydraulic pressure

Surface chloride concentration = **2.2%**; uncertainty factor (water head = 1 m; permeability coefficient = 1e-10 m/s; porosity = 12%)

W/C ratio	Mix	ψ	D_{ca}	Time to corrosion initiation (Year) 45 mm	50 mm	55 mm	60 mm	65 mm	70 mm
0.4	PFA25	0.2477	3.74E-12	4	6	6	7	7	8
0.45	PFA25	0.2503	4.42E-12	4	6	6	7	7	8
0.4	PFA35	0.2477	3.25E-12	4	6	6	7	7	8
0.45	PFA35	0.2503	3.82E-12	4	6	6	7	7	8
0.4	GGBS50	0.2477	3.51E-12	4	6	6	7	8	8
0.45	GGBS50	0.2503	4.14E-12	4	6	6	7	7	8
0.4	GGBS70	0.2477	3.26E-12	4	6	6	7	7	8
0.45	GGBS70	0.2503	3.84E-12	4	6	6	7	7	8

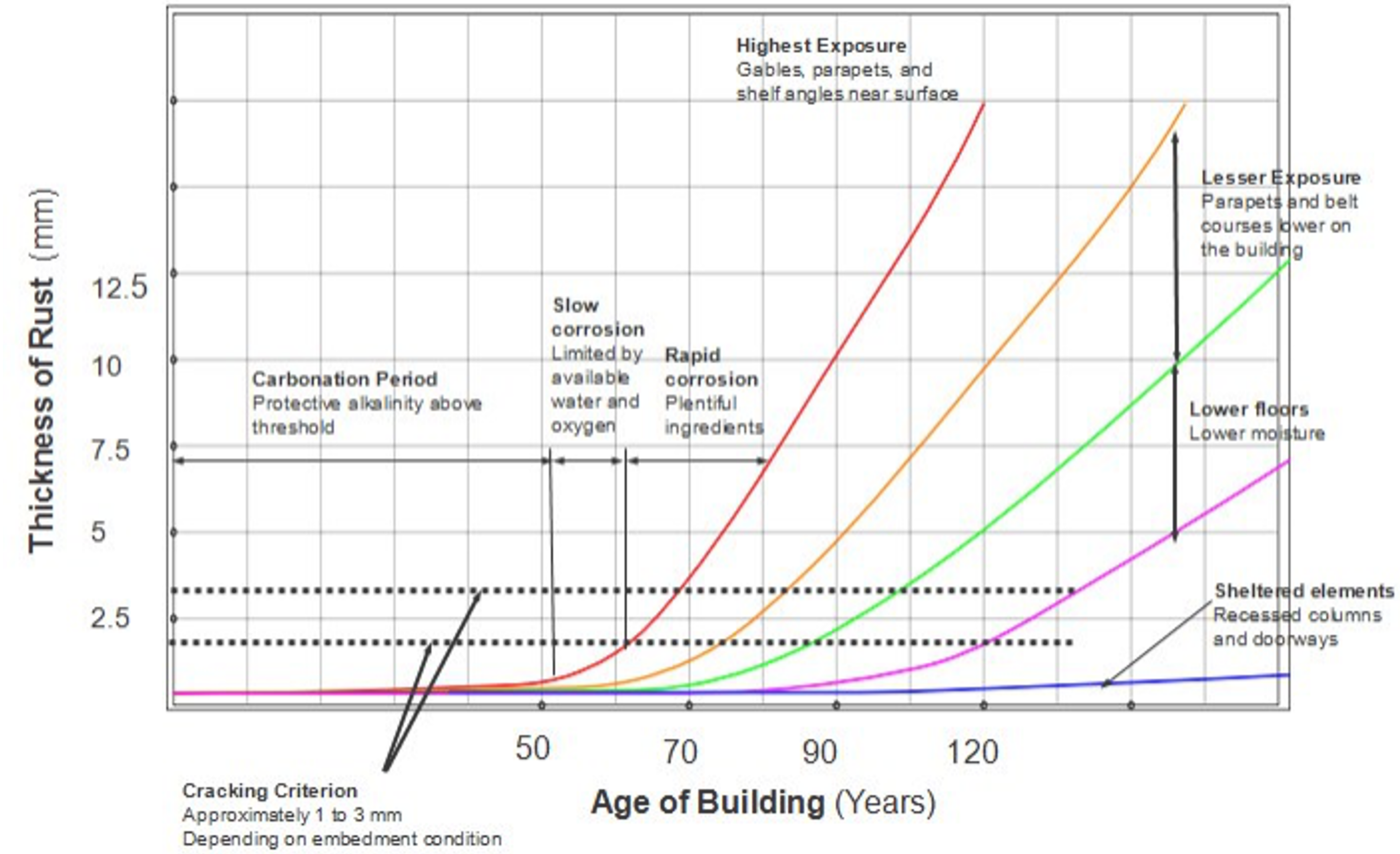
[4] K.D. Stanish, R.D. Hooton and M.D.A. Thomas, Testing the Chloride Penetration Resistance of Concrete: A Literature Review. FHWA Contract DTFH61-97-R-00022 "Prediction of Chloride Penetration in Concrete"

- Rising Sea levels
  - Head Pressure increases chloride diffusion coefficient



Liu and Jiang (2021) Influence of Hydrostatic Pressure and Cationic Type on the Diffusion Behavior of Chloride in Concrete

Considerations/Summary



Modeling Considerations

- Consider Higher CO_2 Emissions
- Develop Water Table Height at End of Service Life
- Use Estimate End of Life Temperature Change
- Account for Extreme Events
- Allow for Diffusion Changes

Considerations/Summary

Preventative Considerations

- Increase concrete cover
- Add supplementary cementitious materials
- Improve crack control
- Utilize corrosion resistant rebar
- Install cathodic prevention

Questions?

Thank you

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