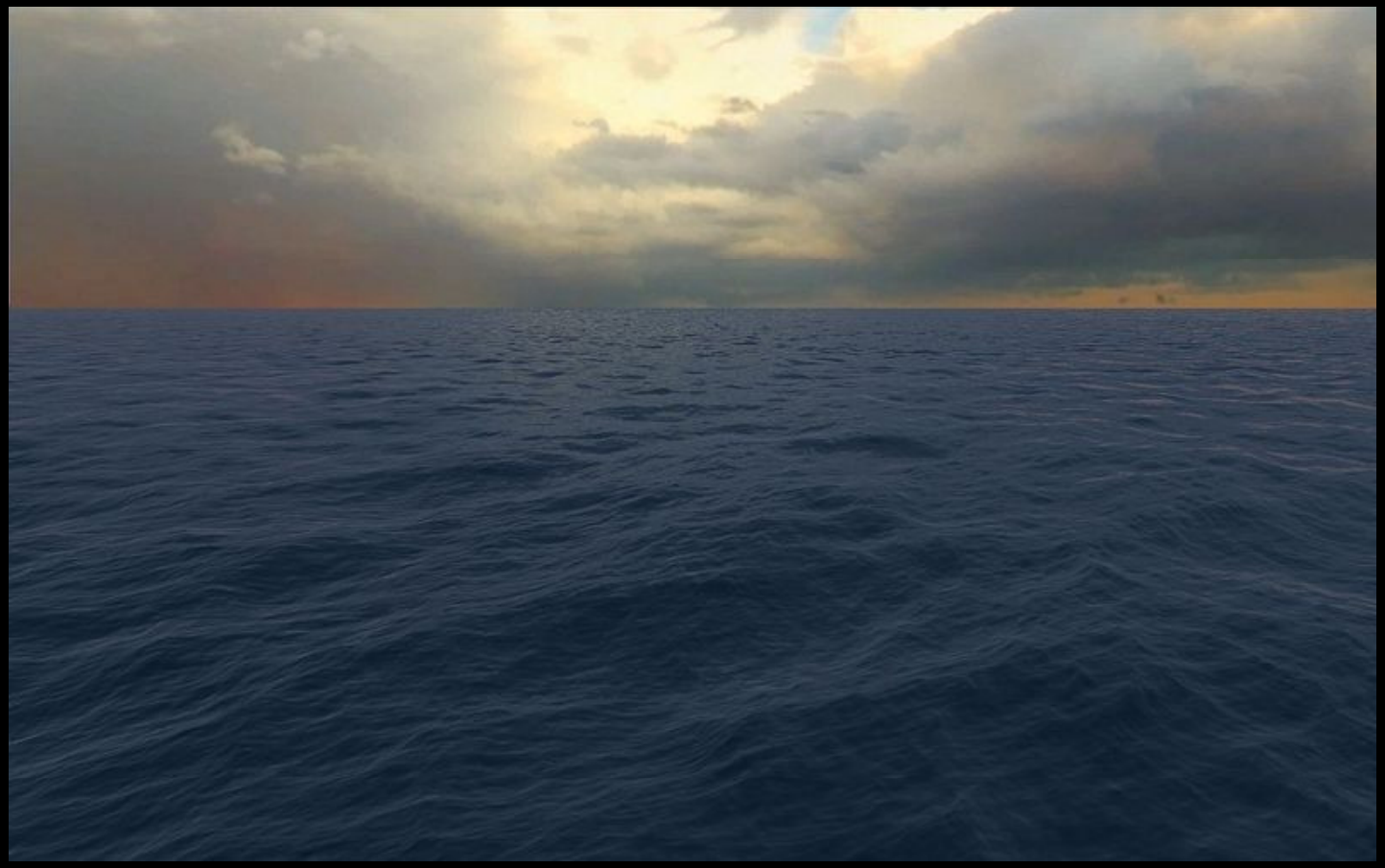
Ocean Surface Simulation



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- DirectX Compute Implementation
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Simulation Overview

- Based on Jerry Tenssendorf's paper "Simulating Ocean Water"
  - Statistic based, not physics based
  - Generate wave distribution in frequency domain, then perform inverse FFT
  - Widely used in movie CGIs since 90s, and in games since 2000s
- In movie CGI: The size of height map is large
  - Titanic, 2048x2048
  - Water World, 2048x2048
  - And more…
- In games: The size of height map is small
  - Crysis, 64x64
  - Resistance 2, 32x32
  - And more…
  - All simulated on CPU (or Cell SPE)

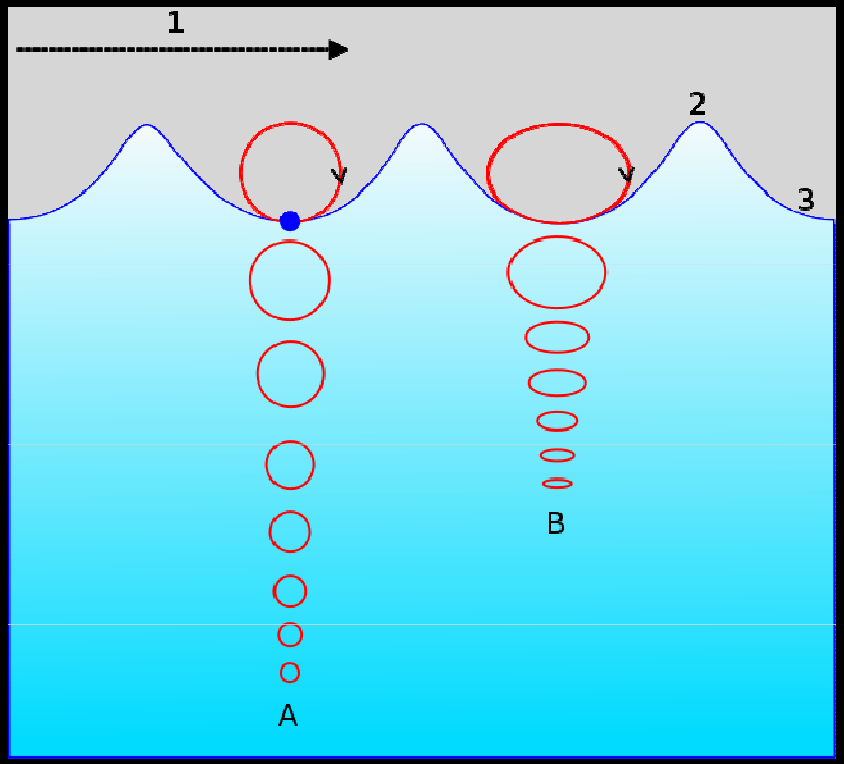
Performance Issues

- The simulation require to generate the displacement map in real-time
- Computing FFT on CPU becomes the bottleneck when the displacement map gets larger
  - Larger texture also takes longer time on CPU-GPU data transfer
  - However, large displacement map is a must-have for detailed wave crests
- GPU computing is really good at FFT
  - Multiple 512x512 transforms can be performed in trivial time on high-end GPUs
  - Multiple 1024x1024 transforms are affordable for high quality real-time rendering

The Algorithm: Wave Composition

- The ocean surface is composed by enormous simple waves
- Each simple wave is a hybrid sine wave (Gerstner wave)
  - A mass point on the surface is doing vertical circular motion

$$\mathbf{x} = \mathbf{x}_0 - (\mathbf{k}/k)A\sin(\mathbf{k}\cdot\mathbf{x} - \omega t)$$
$$y = A\cos(\mathbf{k}\cdot\mathbf{x} - \omega t)$$



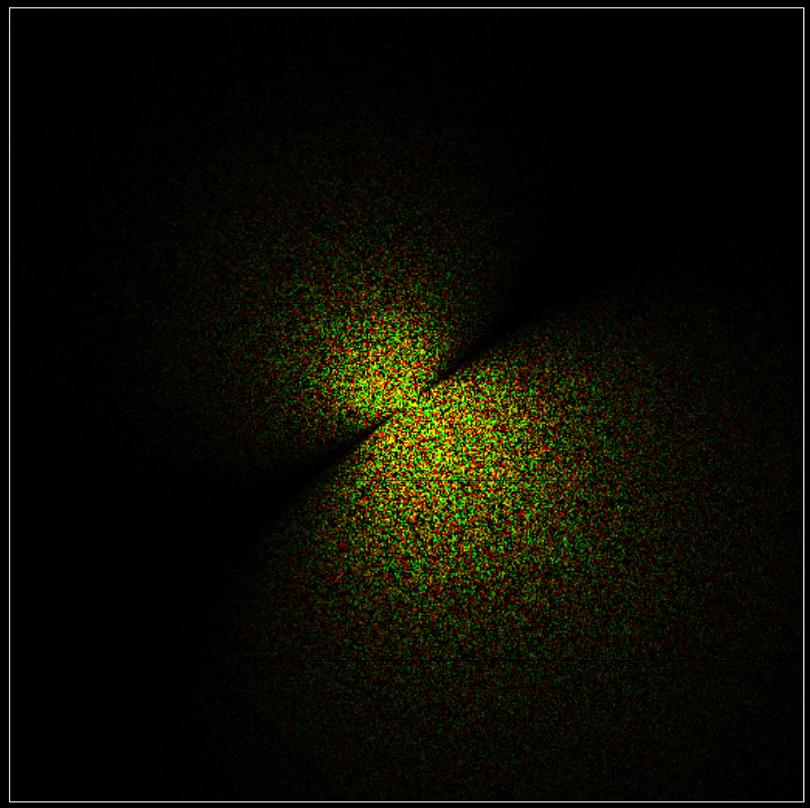
The Algorithm: Statistic Model

- The distribution of wave length, speed and amplitude are following several statistic models
  - **Phillips spectrum** is one mostly used practical model: Gauss function modulated by wind direction

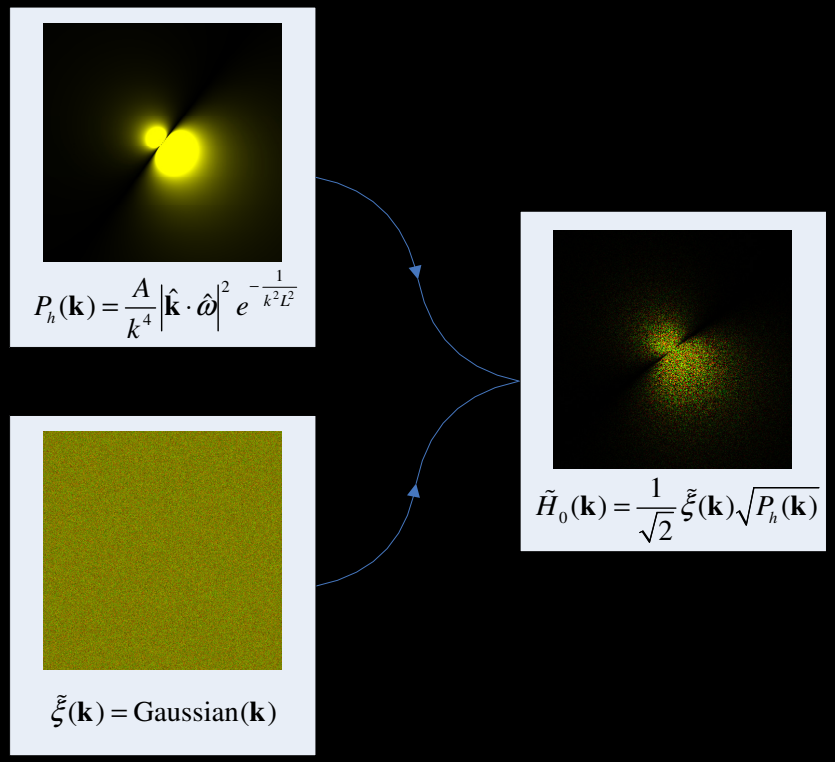
$$P_h(\mathbf{k}) = \frac{A}{k^4}\left|\mathbf{k}\cdot\boldsymbol{\omega}\right|^2 e^{-\frac{1}{k^2L^2}}$$

- Generated in frequency domain at the initial time

$$\tilde{H}_0(\mathbf{k}) = \frac{1}{\sqrt{2}}\tilde{\xi}(\mathbf{k})\sqrt{P_h(\mathbf{k})}$$



The Diagram of Generating Initial Spectrum



The Algorithm: Displacement Map

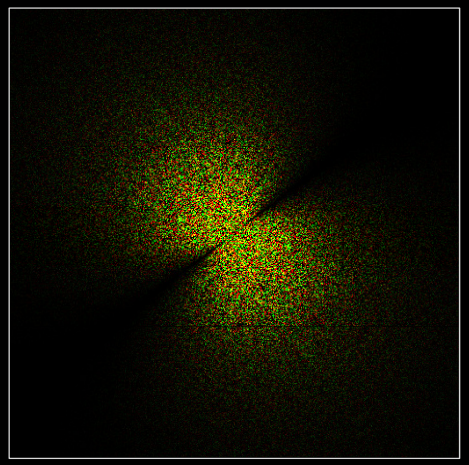
- Update three spectrums for each displacement direction at runtime
  - Z for “height” field

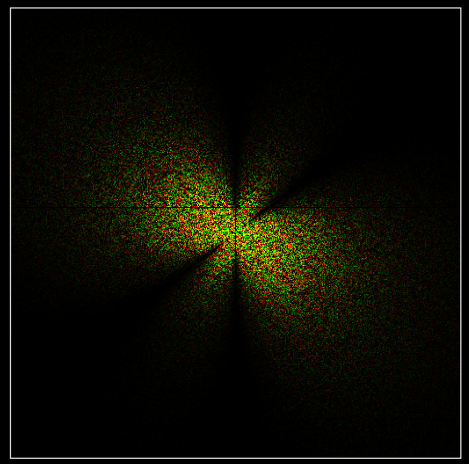
$$\tilde{H}(\mathbf{k},t) = \tilde{H}_0(\mathbf{k})e^{i\omega t} + \tilde{H}_0^*(-\mathbf{k})e^{-i\omega t}$$

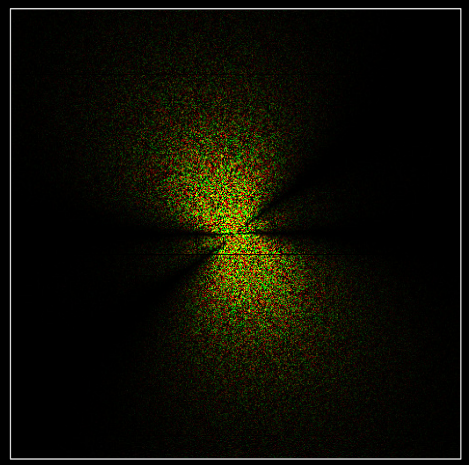
  - XY for “choppy” field

$$\tilde{\mathbf{D}}(\mathbf{k},t) = i\frac{\mathbf{k}}{k}\tilde{H}(\mathbf{k},t)$$

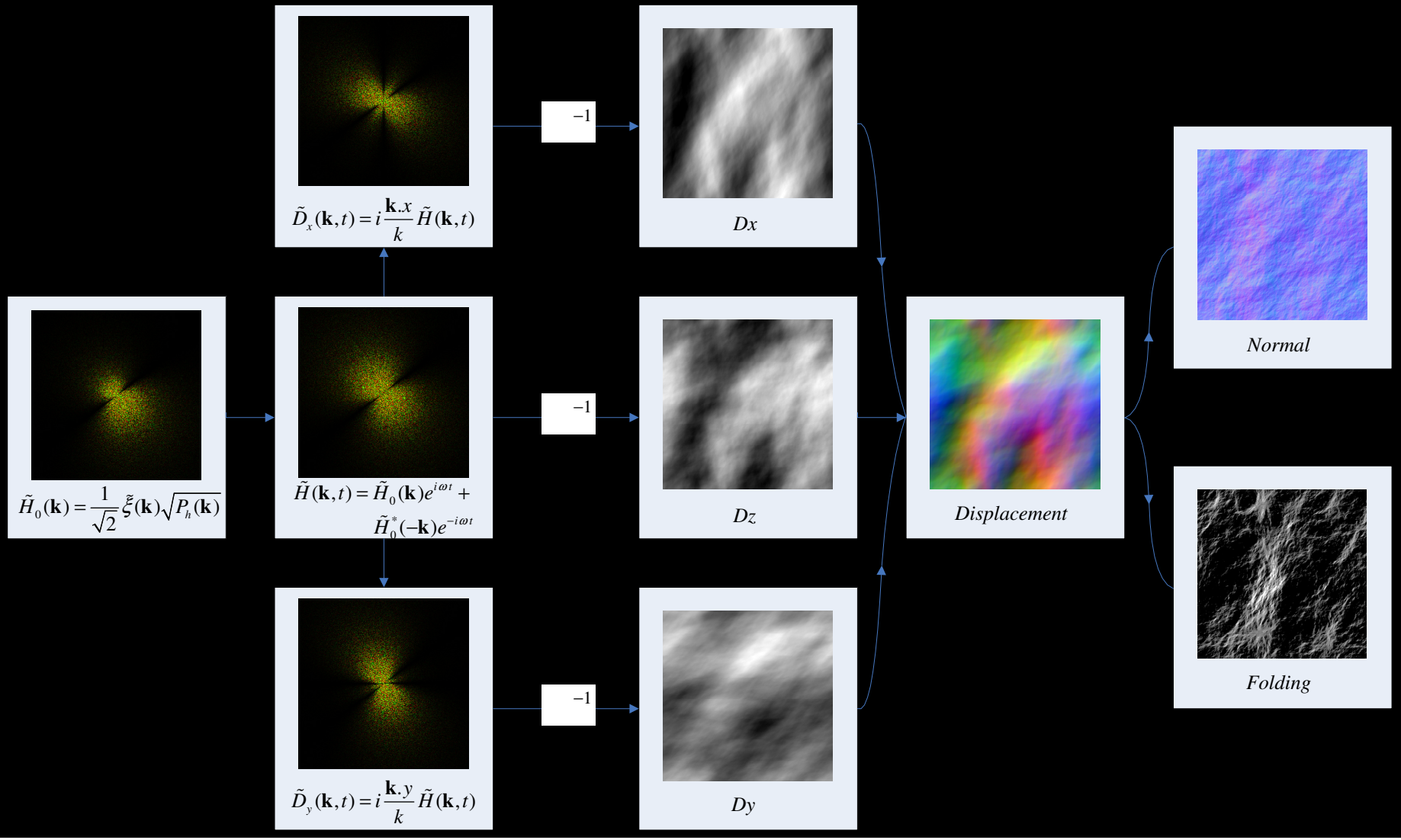
- Perform inverse FFT on three spectrums
- Surface normal and other data are generated from displacement map



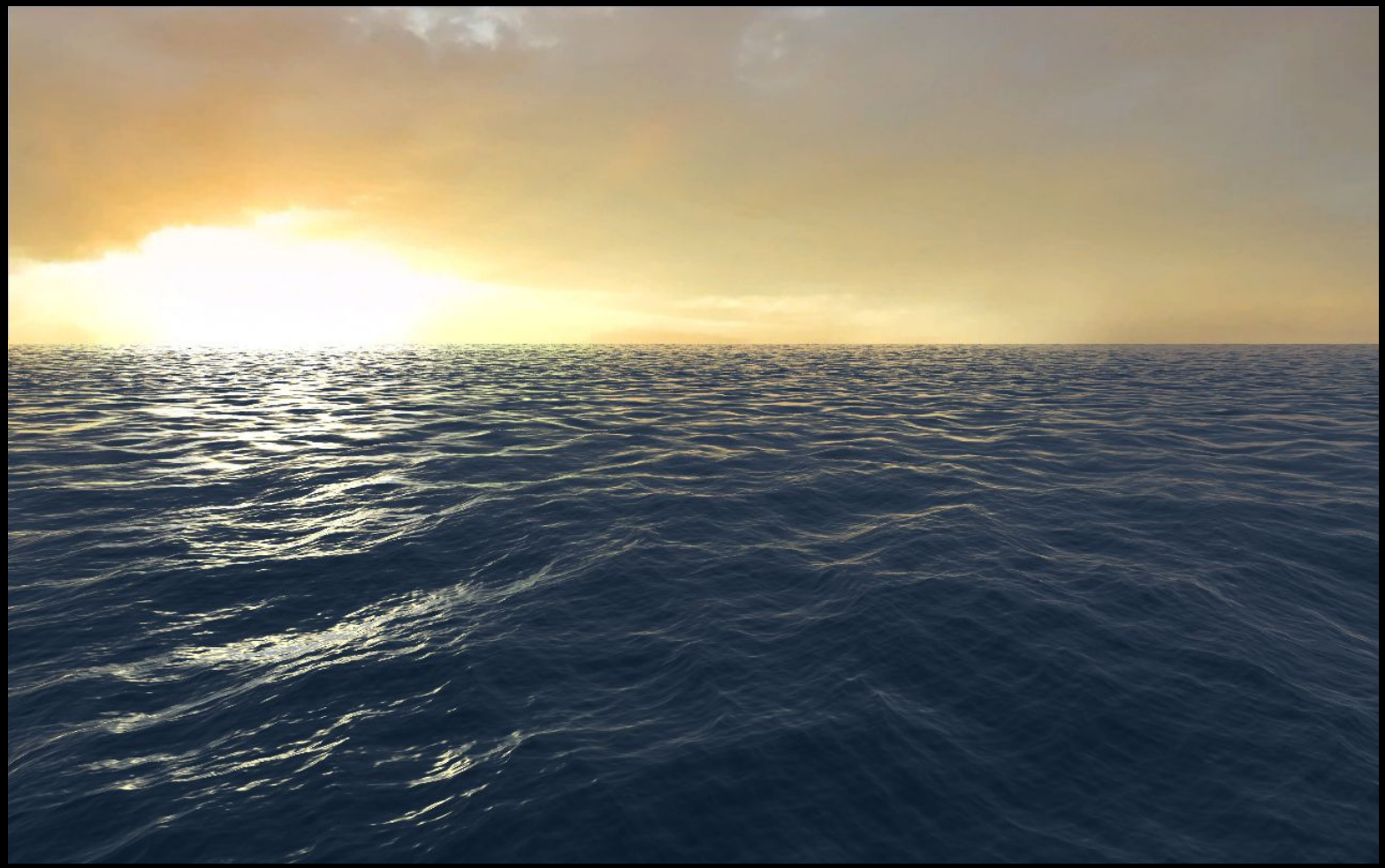




The Diagram of Updating Displacement Map



Rendering



Screen Space vs. World Space

- **Screen Space**

  Pro
  - Minimal mesh wastage
  - Can be extended to horizon easily

  Con
  - Distracting alias at distance due to undersampling
  - Require huge off-screen mesh chunks to cover gaps along the screen edges

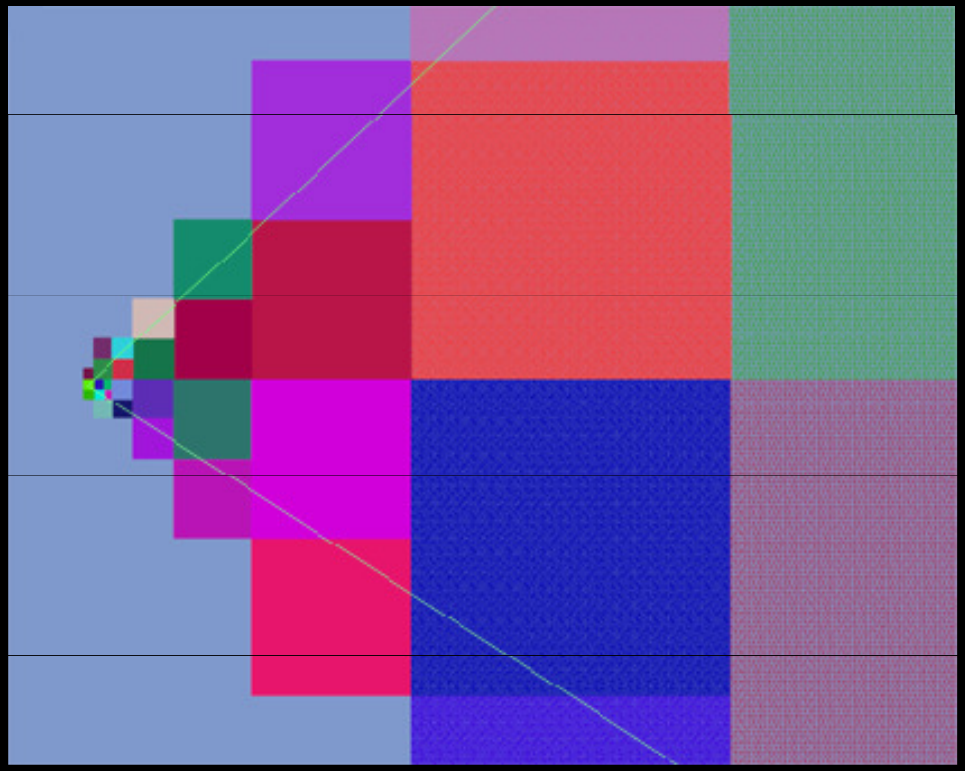
- **World Space**

  Pro
  - Can be mapped to displacement map straightforwardly
  - No undersampling alias

  Con
  - Need more complicated way extending to horizon
  - Produce many sub-pixel triangles at distance

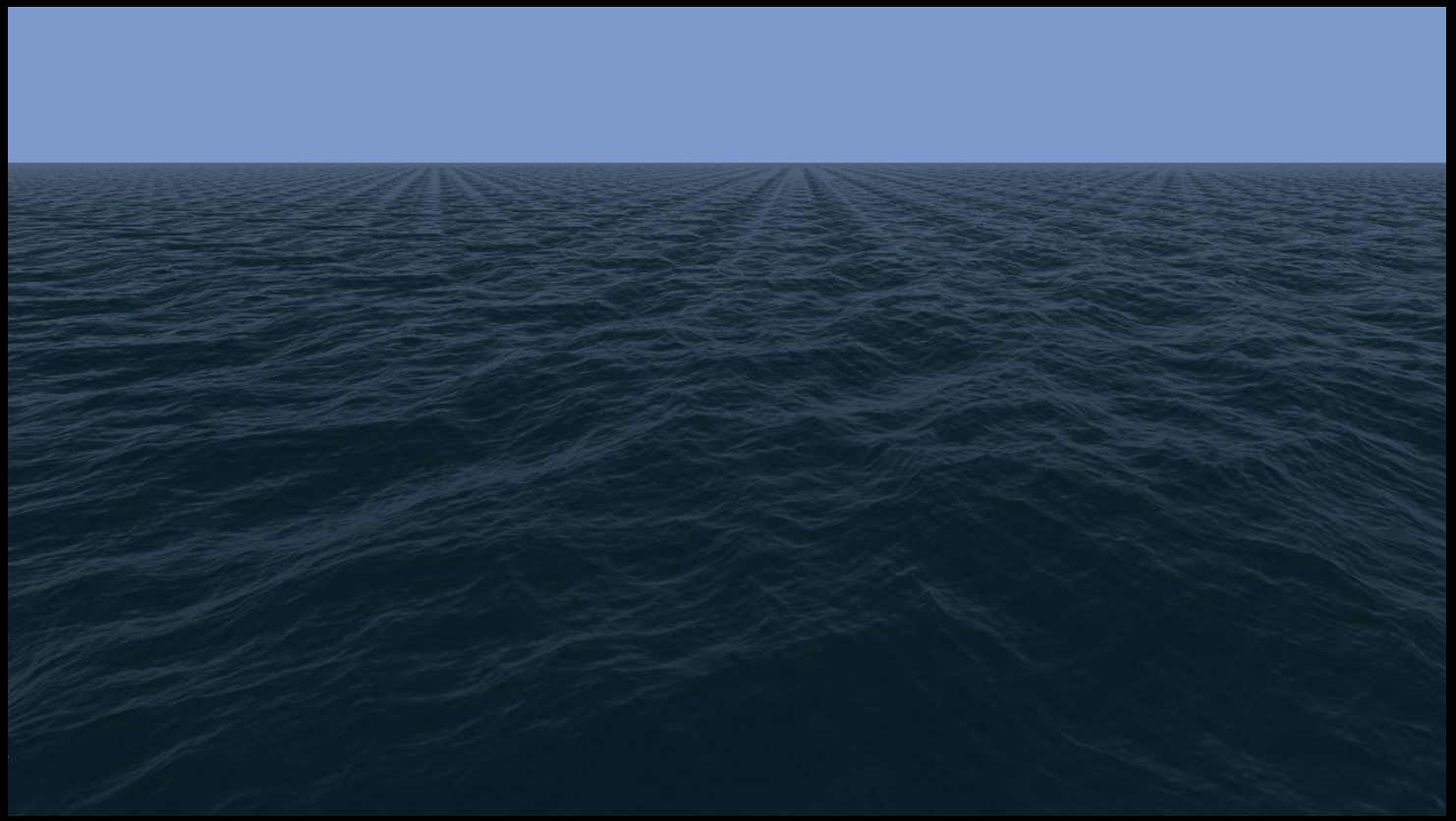
World Space Rendering

- We use world space rendering in the demo
- The mesh is created at half resolution of the displacement map
  - In the demo, 256x256
- Quad-tree is employed for frustum culling and mesh LOD



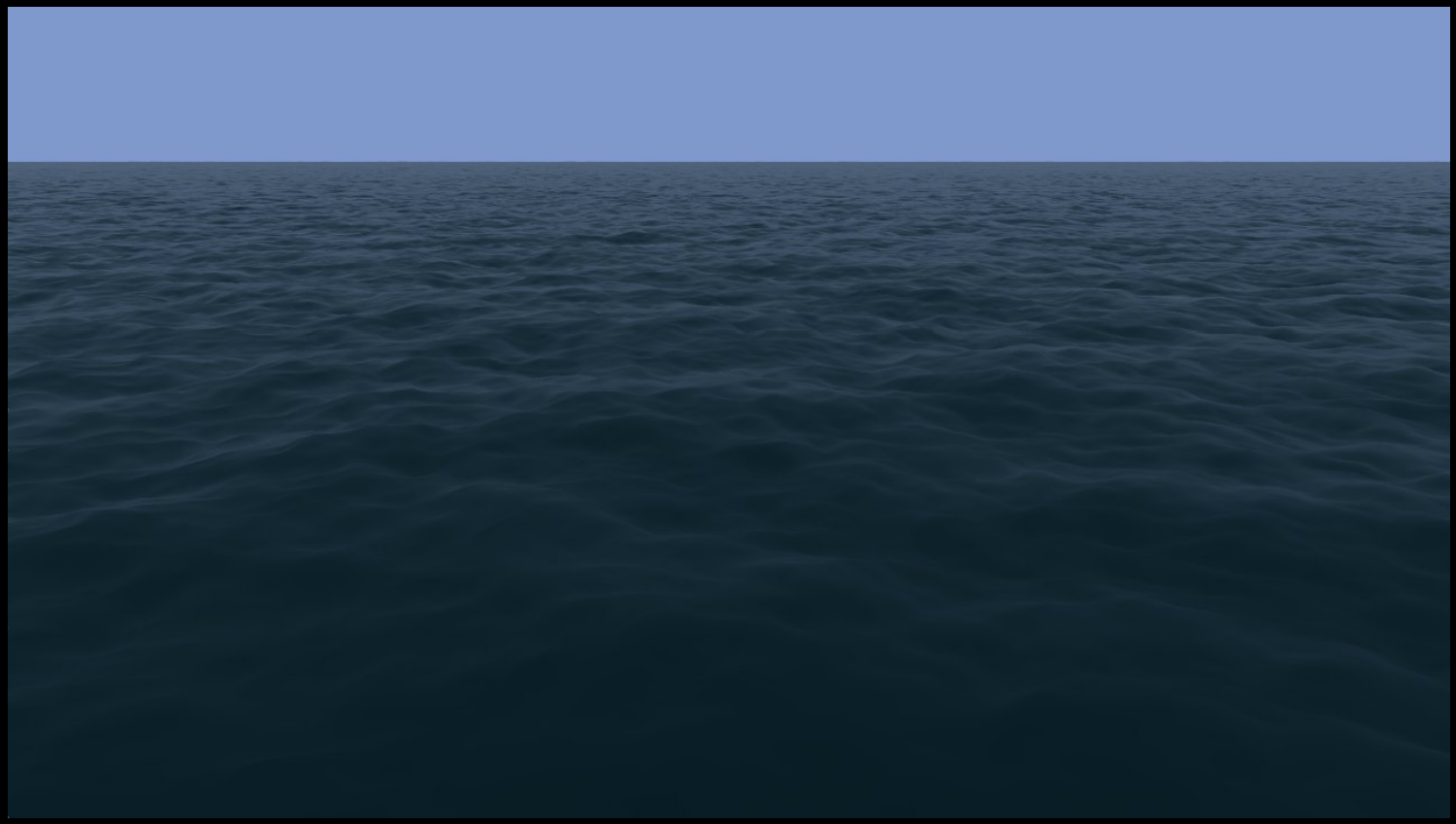
Tiling Artifact Removing (1)

- FFT only produce periodic pattern
  - The repeated pattern becomes a major distraction at distance
  - But looks okay at near sight



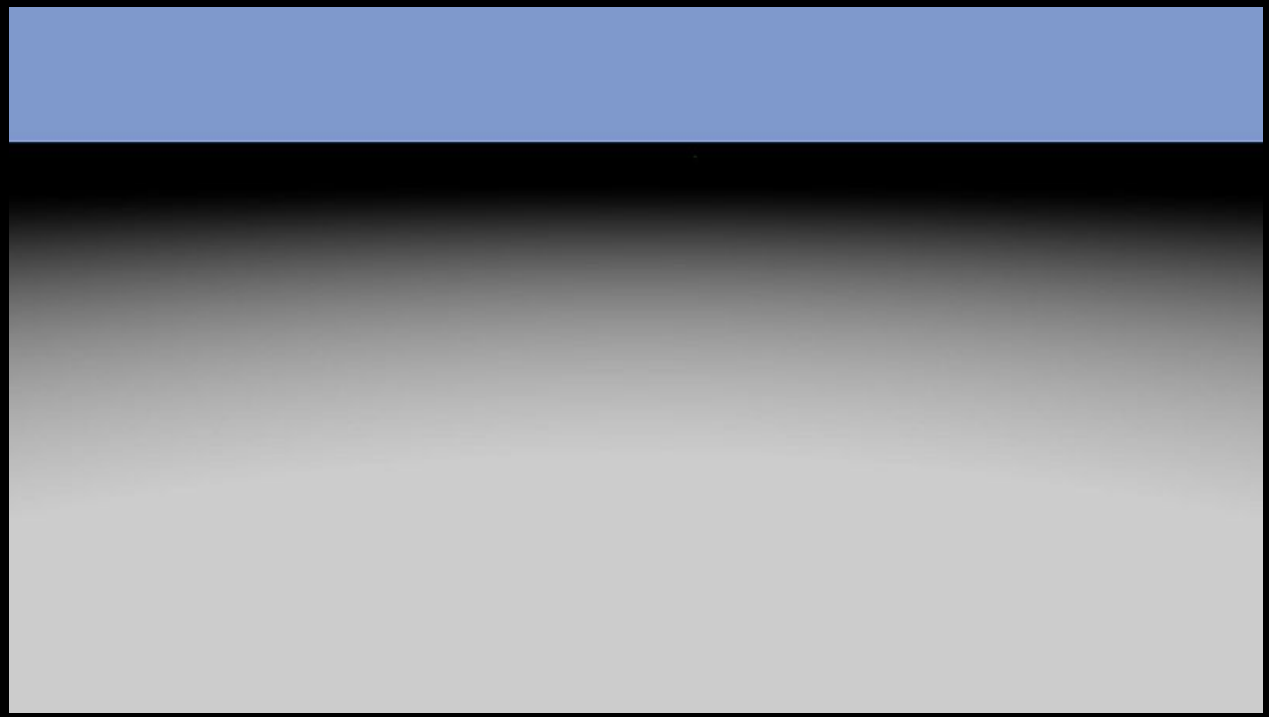
Tiling Artifact Removing (2)

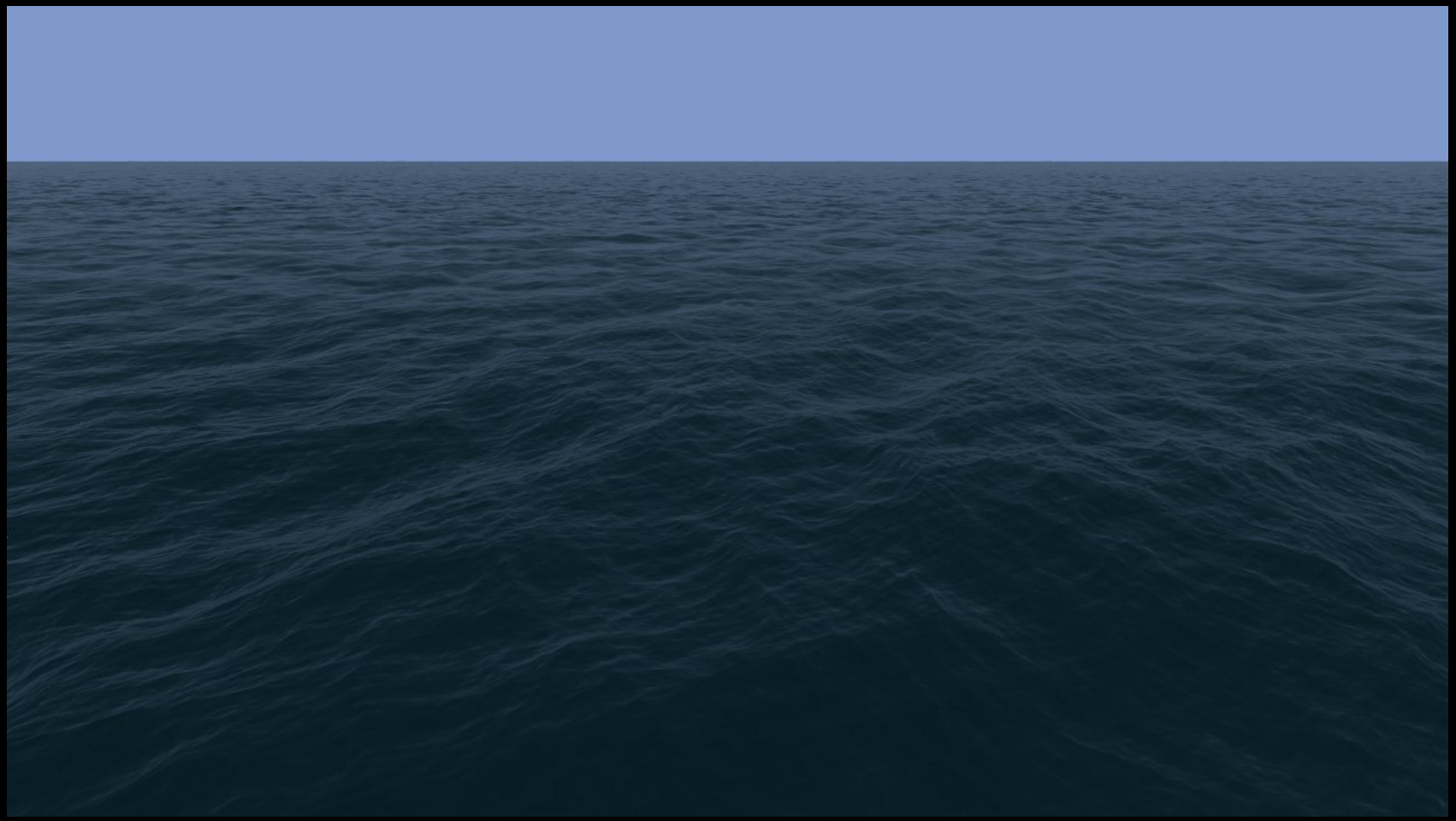
- Perlin noise composed crests yield no tiling artifact
  - But lack of details at near sight



Tiling Artifact Removing (3)

- Solution: blend Perlin and FFT generated crests
  - Effective and simple
  - We do tried texture synthesize based method, but which works poorly and not worthy to do in real-time





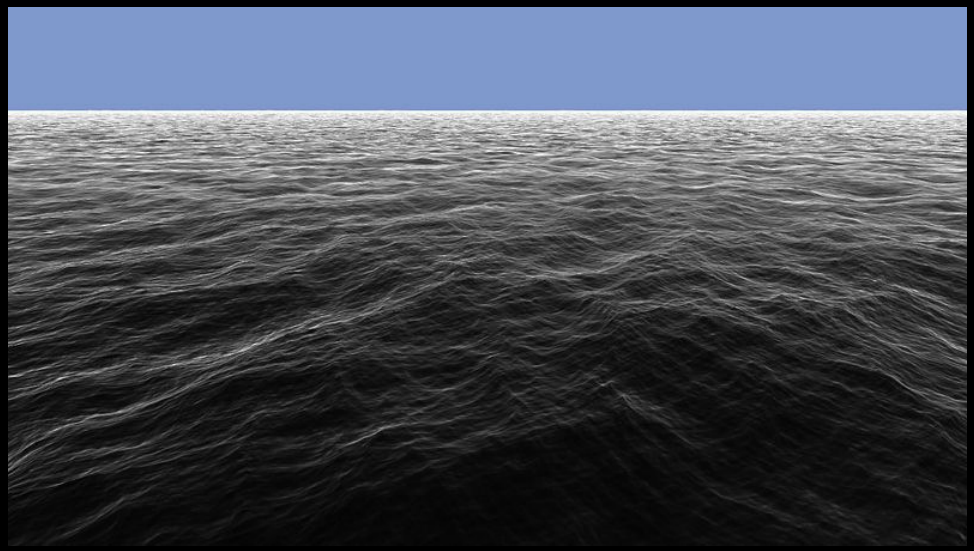
The result of blending FFT and Perlin noise

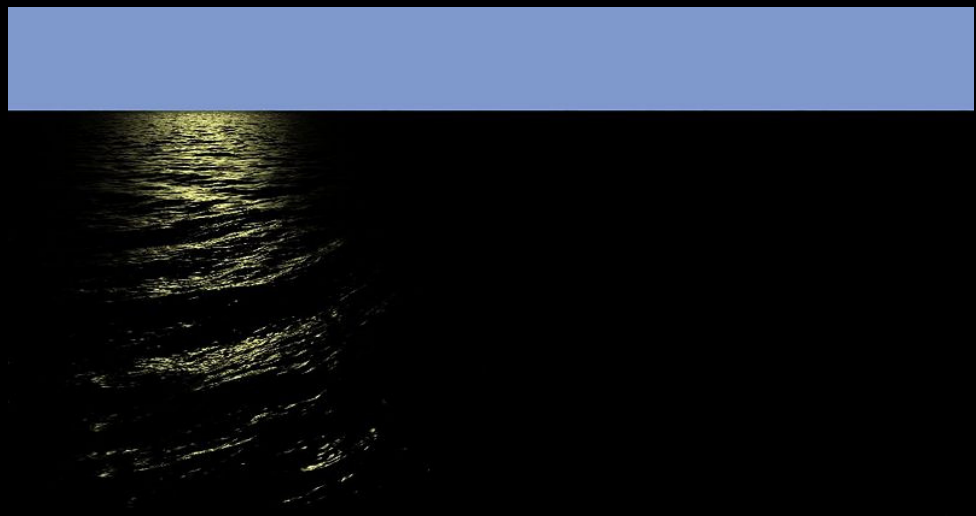
Ocean Shading (1)

- The demo only rendered for deep ocean water
  - Shallow water rendering is much more complicated
- Shading components
  - Water body color: using a constant color
  - Fresnel term for reflection: read from a pre-computed texture
  - Reflected color: using a small cubemap blend with a constant sky color
  - Vertical streak: computed from a modified specular term

Ocean Shading (2)

- Fresnel term (left) and sun streak (right)





DirectX Compute Implementation

- Use DX Compute to
  - Update three spectrums each frame
  - Perform three 512x512 inverse FFTs each frame
- Use Pixel Shader to
  - Read the results from FFT and interleave the data into displacement map
  - Generate normal map

Details on DX Compute code

- Inverse FFT
  - Currently, only 512x512 transform is implemented in the SDK sample
    - Higher than 1024x1024 will produce visible artifact due to FP precision
  - Using CS4.0 to run on DX10 level GPU (G8x and later)
  - Using complex-to-complex transform for better coalescing performance
- UAV usage (Unordered Access View)
  - CS4.x only supports 1 UAV per compute shader
  - To output to three buffers for the three spectrums, just allocate one big buffer and manage the offsets for each buffer
  - A pixel shader is employed to read the transformed data from the UAV and interleave them into a FP32x4 texture

Performance

- The performance is bound by texture
  - FFT takes trivial time to complete on most GPUs.
  - Increasing AF level can help the image quality, but decrease the framerate steeply

Acknowledgement

- Thanks for Victor Podlozhnyuk for providing FFT code, Simon Green for various suggestions, Cyril Zeller and Cem Cebenoyan for supporting doing this demo