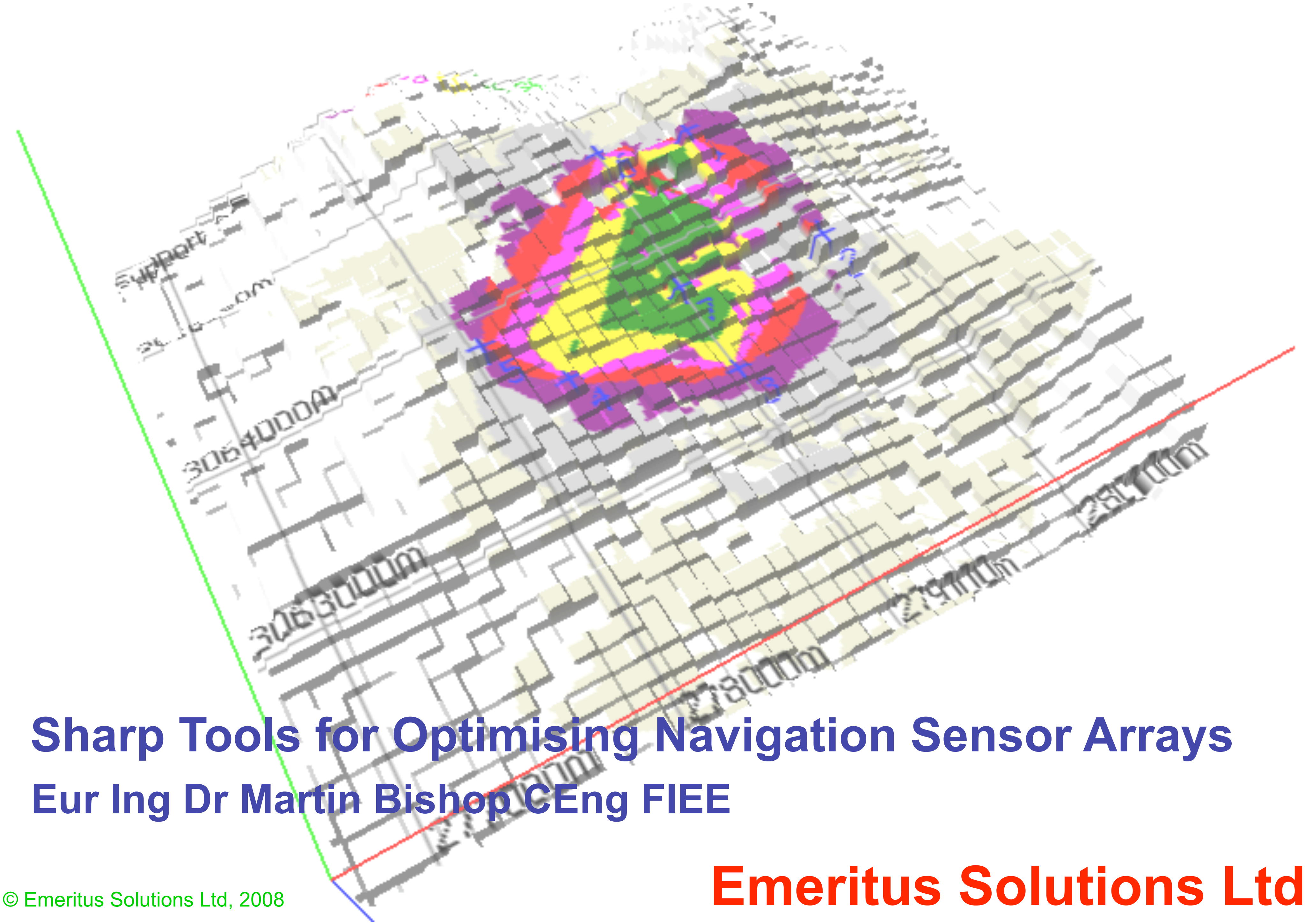

Sharp Tools for Optimising Navigation Sensor Arrays

Eur Ing Dr Martin Bishop CEng FIEE

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Sharp Tools for Optimising Navigation Sensor Arrays

- Synopsis
  - What's the problem
  - What are the sharp tools
  - The math in a nutshell
  - Gulf of Mexico bottom positioning example
  - NW Europe Loran Chain optimal station locations example

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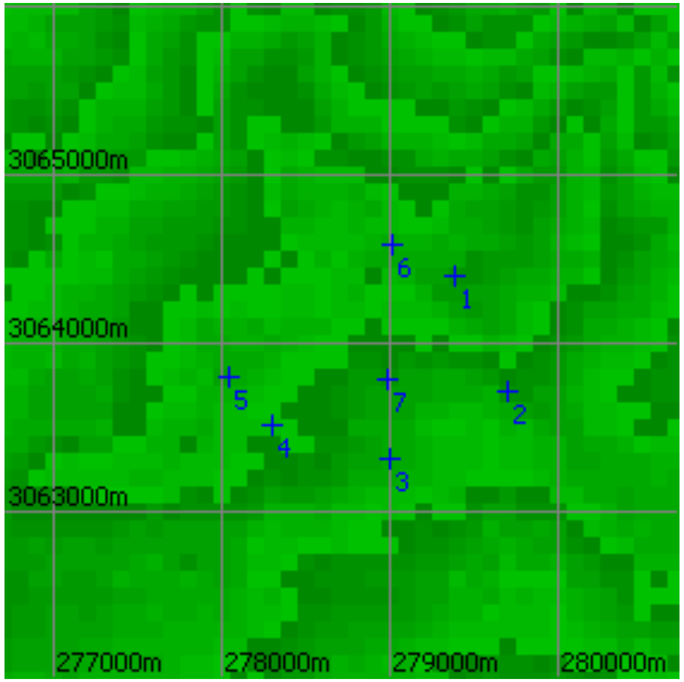
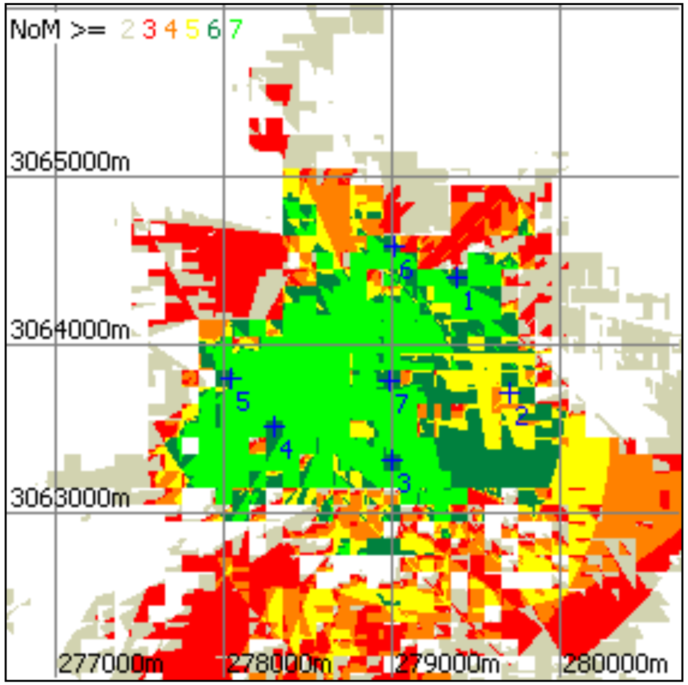
Gulf of Mexico : Near Bottom Positioning



Bathymetry



Stations in View

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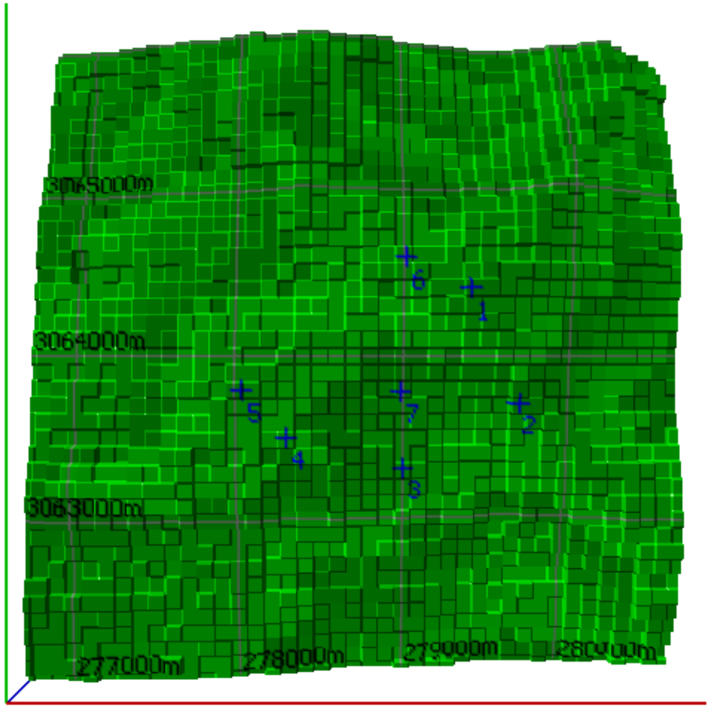
Gulf of Mexico : Bathymetry



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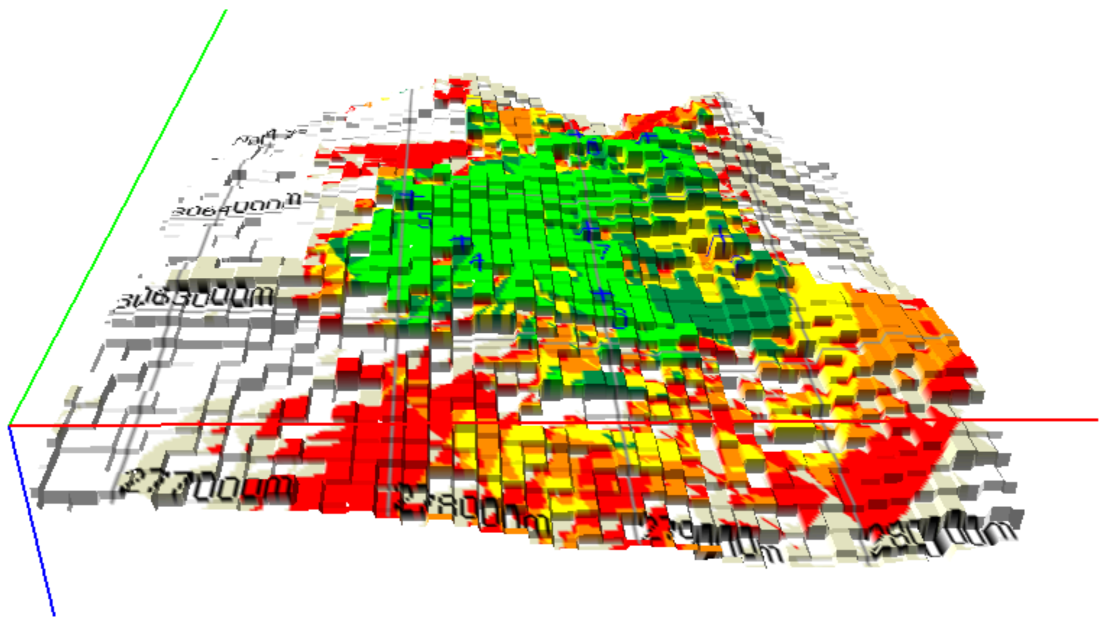
Gulf of Mexico : NoM



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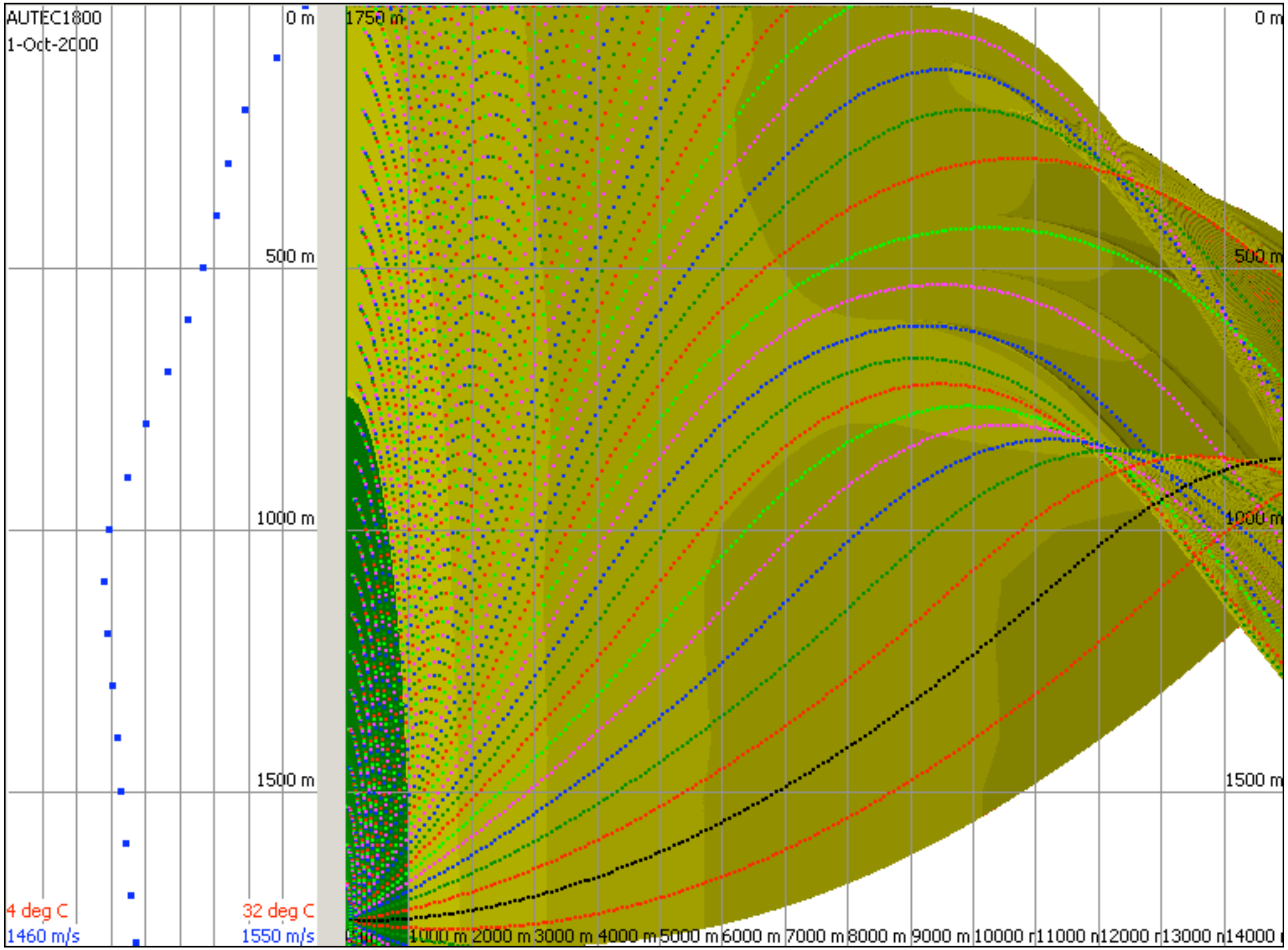
Gulf of Mexico : Sound Propagation



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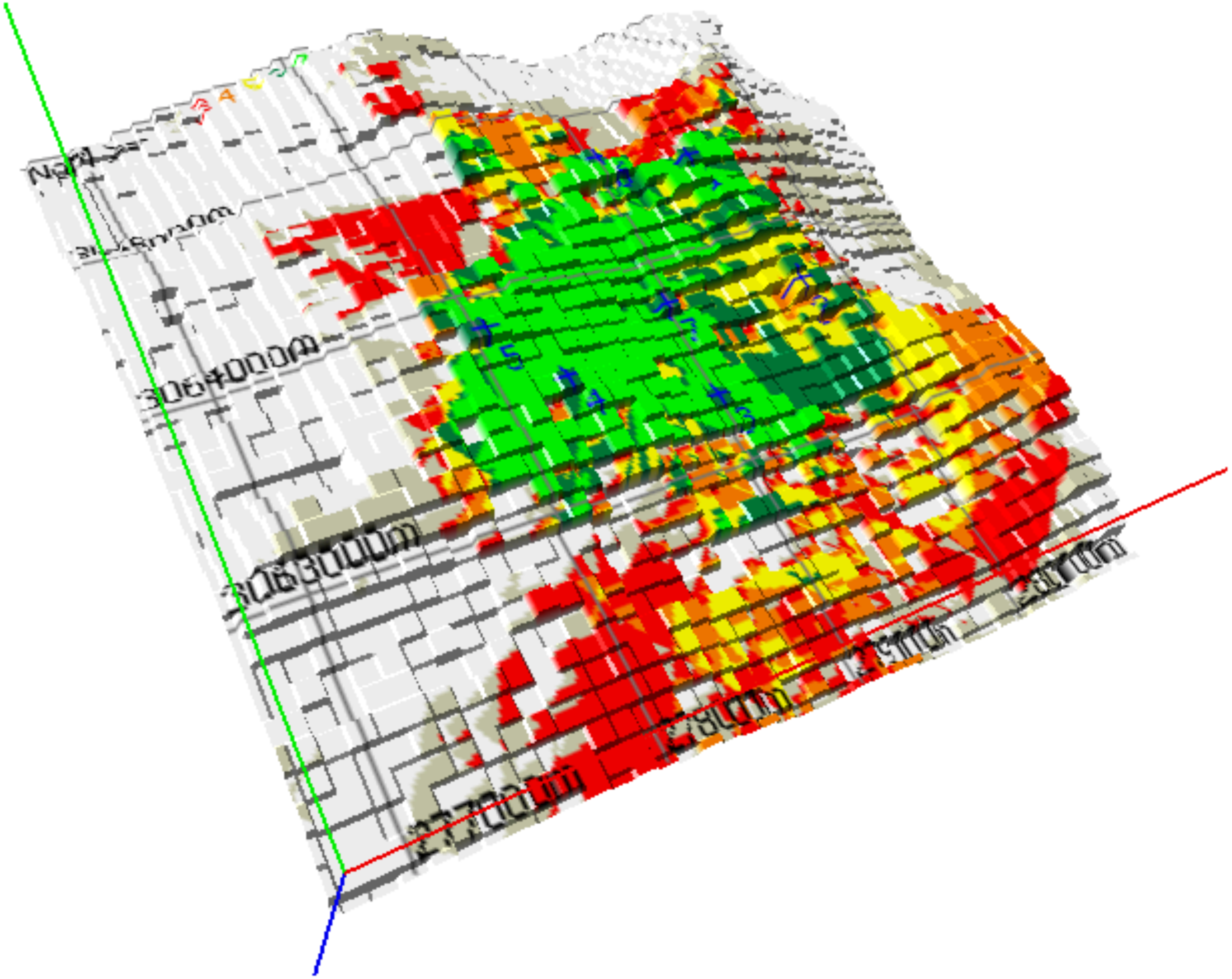
Gulf of Mexico : 3-D Depth and Coverage



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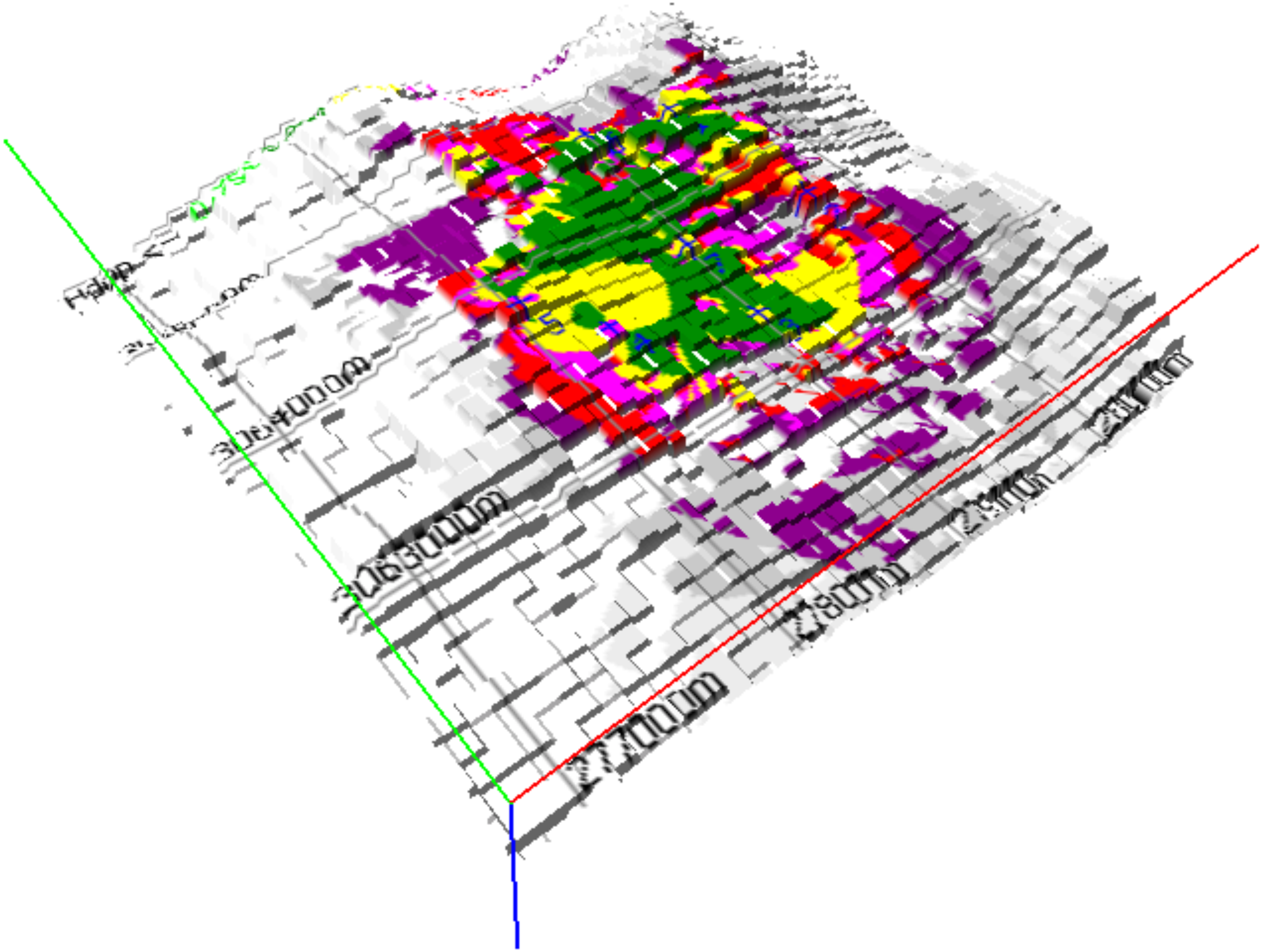
Gulf of Mexico : H dop



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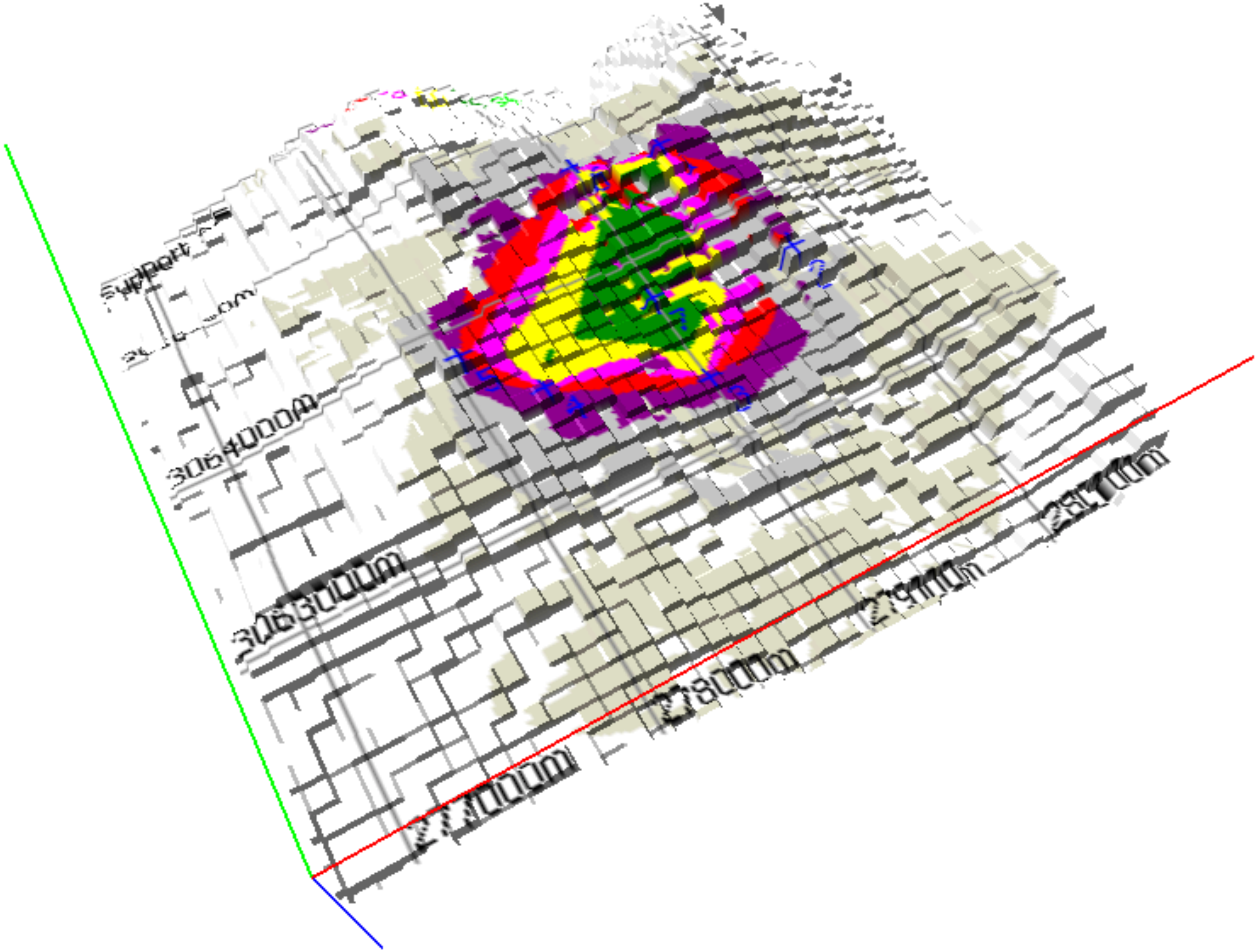
Gulf of Mexico : Support



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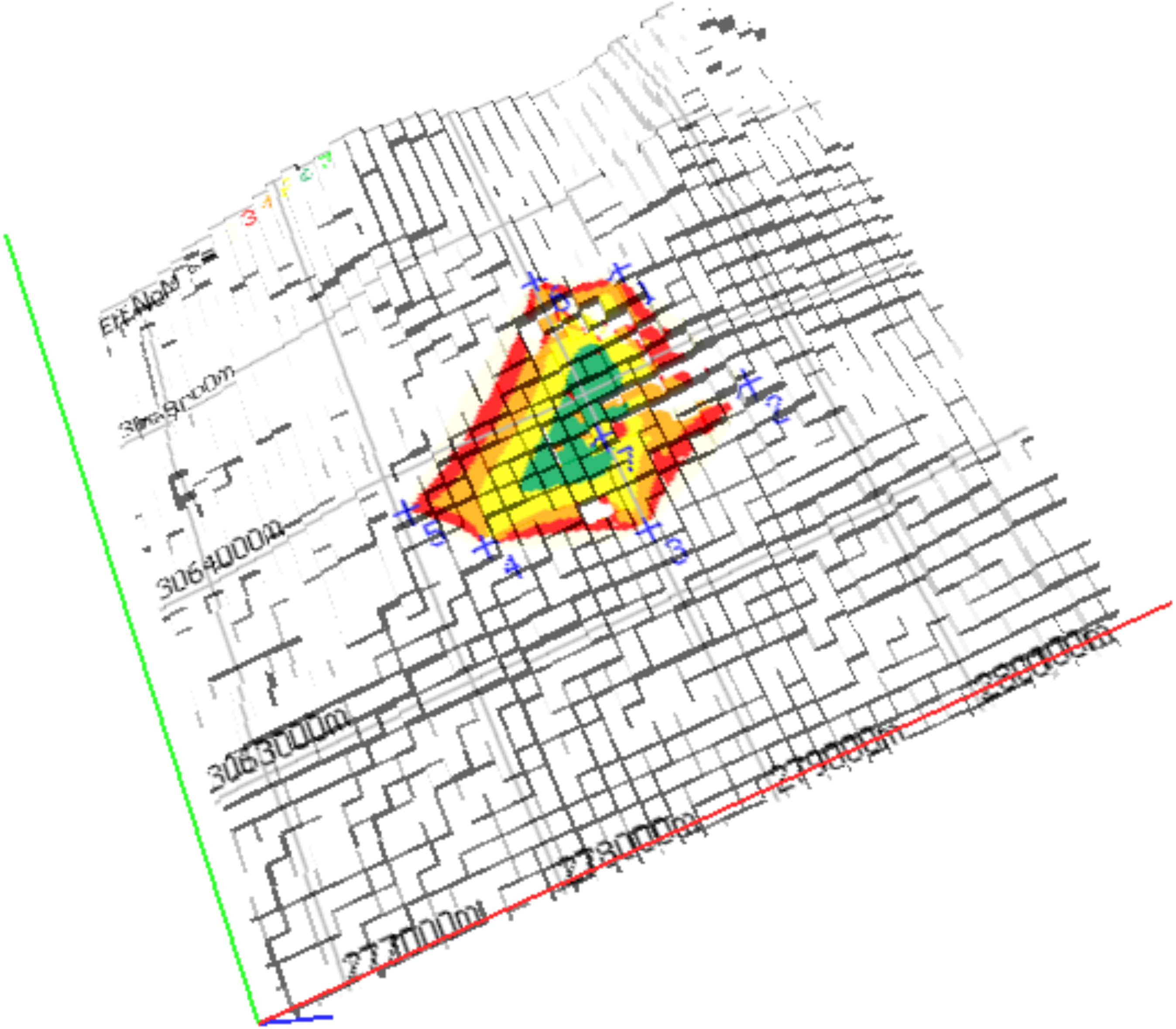
Gulf of Mexico : N eff



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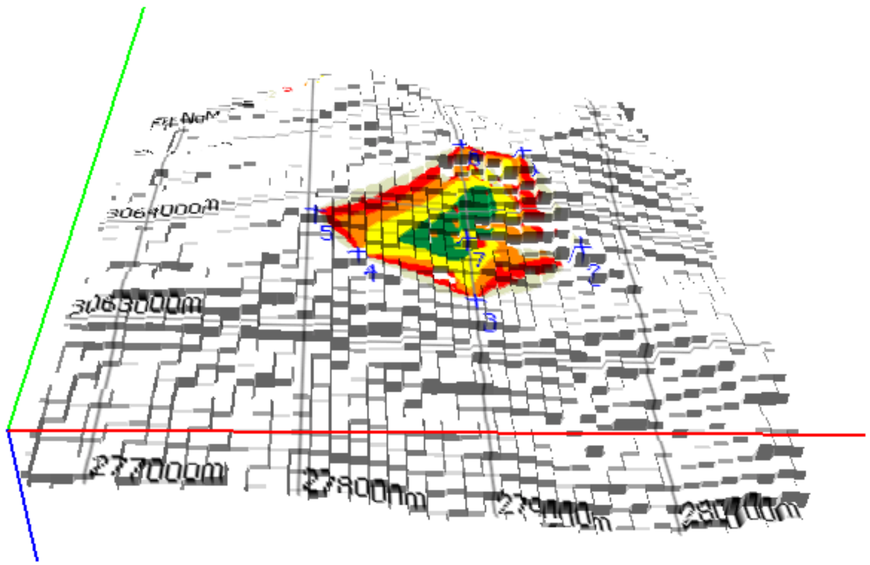
Gulf of Mexico : N eff



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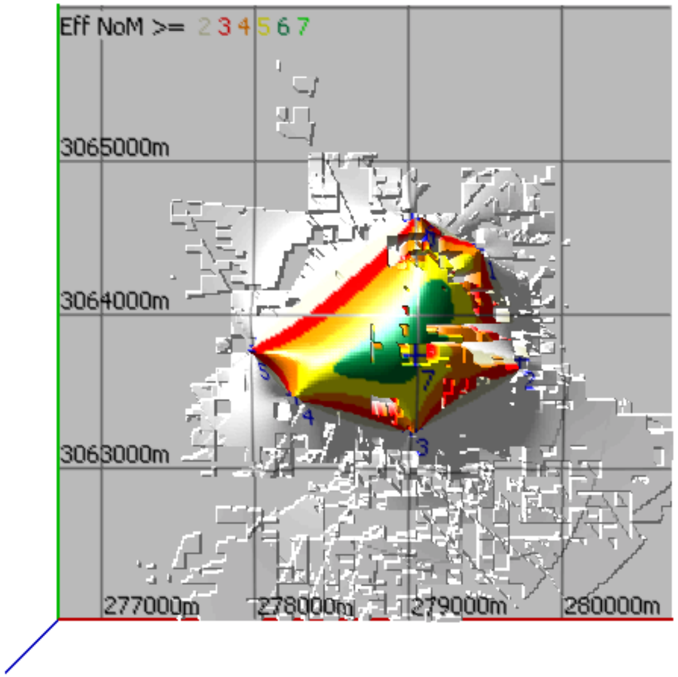
Gulf of Mexico : N eff



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The Math in a Nutshell

$\underline{h}_i = [\underline{r}_i : 1]^T$: augmented direction cosines

$\underline{H} = [\underline{h}_i \,..\, \underline{h}_n]^T$

$$\mathrm{cov}(\theta) = \sigma_r^2 (\underline{H}\,\underline{H}^T)^{-1} = \begin{bmatrix} \sigma_{xx}^2 & . & . & . \\ . & \sigma_{yy}^2 & . & . \\ . & . & \sigma_{zz}^2 & . \\ . & . & . & \sigma_{tt}^2 \end{bmatrix}$$

$$Hdop = \sqrt{(\underline{H}^T \underline{H})^{-1}{}_{xx} + (\underline{H}^T \underline{H})^{-1}{}_{yy}} = \sqrt{(\sigma_{xx}^2 + \sigma_{yy}^2)/\sigma_r^2}$$

$$Gdop = \sqrt{(\underline{H}^T \underline{H})^{-1}{}_{xx} + (\underline{H}^T \underline{H})^{-1}{}_{yy} + (\underline{H}^T \underline{H})^{-1}{}_{zz} + (\underline{H}^T \underline{H})^{-1}{}_{tt}} = \sqrt{(\sigma_{xx}^2 + \sigma_{yy}^2 + \sigma_{zz}^2 + \sigma_{tt}^2)/\sigma_r^2}$$

- A relationship between Gdop and N
  - Gdop = 2 / √N -- A lower bound on Gdop for N sensors
- Hz Support = Projected area of DCs / area of unit circle
- An expression for Tdop and Clock sensitivity
  - $\ell = \sum h_j$ -- Sum of the direction cosines
  - Tdop = $\sqrt{(1 / (n-\ell^T M \ell))}$ -- An insightful expression for Tdop
- The Bad Geometry or Clock Penalty term
  - $M_{clock} = M\ell\ell^T M / (n-\ell^T M\ell)$ -- Extra DOP due to estimating the clock

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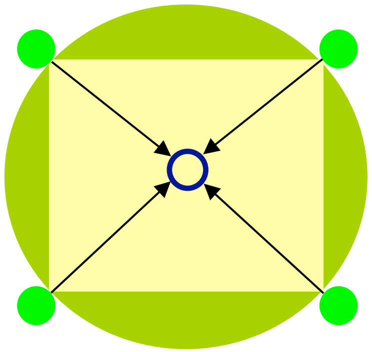
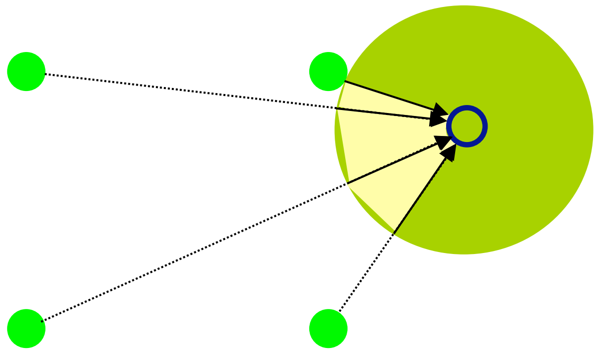
Support and Sensitivity : Graphical Examples

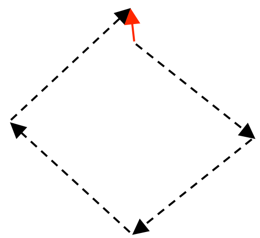


Support ~ 90%

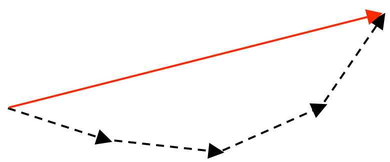


Support ~ 20%

N	DOP
7	0.756
6	0.817
5	0.894
4	1.000
3	1.155
2	1.414
1	2.000
0.25	4.000



Neff ~ 4



Neff ~ 0

DOP = $2 / \sqrt{N}$

Sensitivity to clock bias, noise and speed of sound

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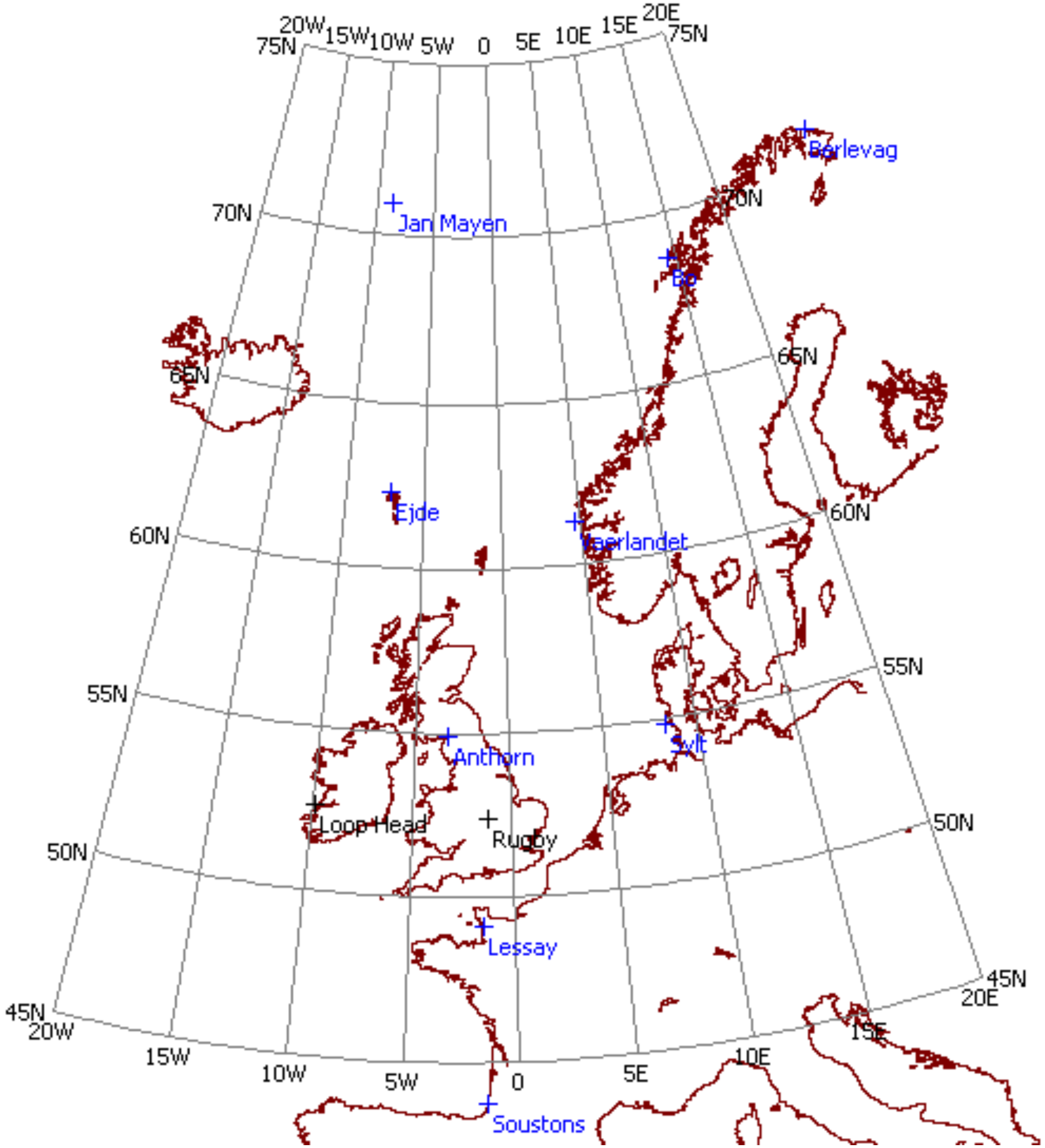
Sharp Tools for Optimising Navigation Sensor Arrays

- What are the problems with underwater positioning
  - Clock performance, especially performance v power
  - Propagation velocity, at best poorly known
  - Multipath; Surface reverberation; Shadow zones; …

- What are the Magic Bullets
  - Working inside the array
  - Using symmetric sensor arrays
  - Analysing the propagation conditions
  - Analysing and refining the range geometry
  - Perform support / Neff / DOP analysis
  - Assess, analyse and resolve second order issues
  - Reviewing the slant range measurements
  - Post process system data for accuracy and insight
  - OpenGL / GPUs / Quaternions / Mathematics & Statistics

NW Europe : Loran Transmitters



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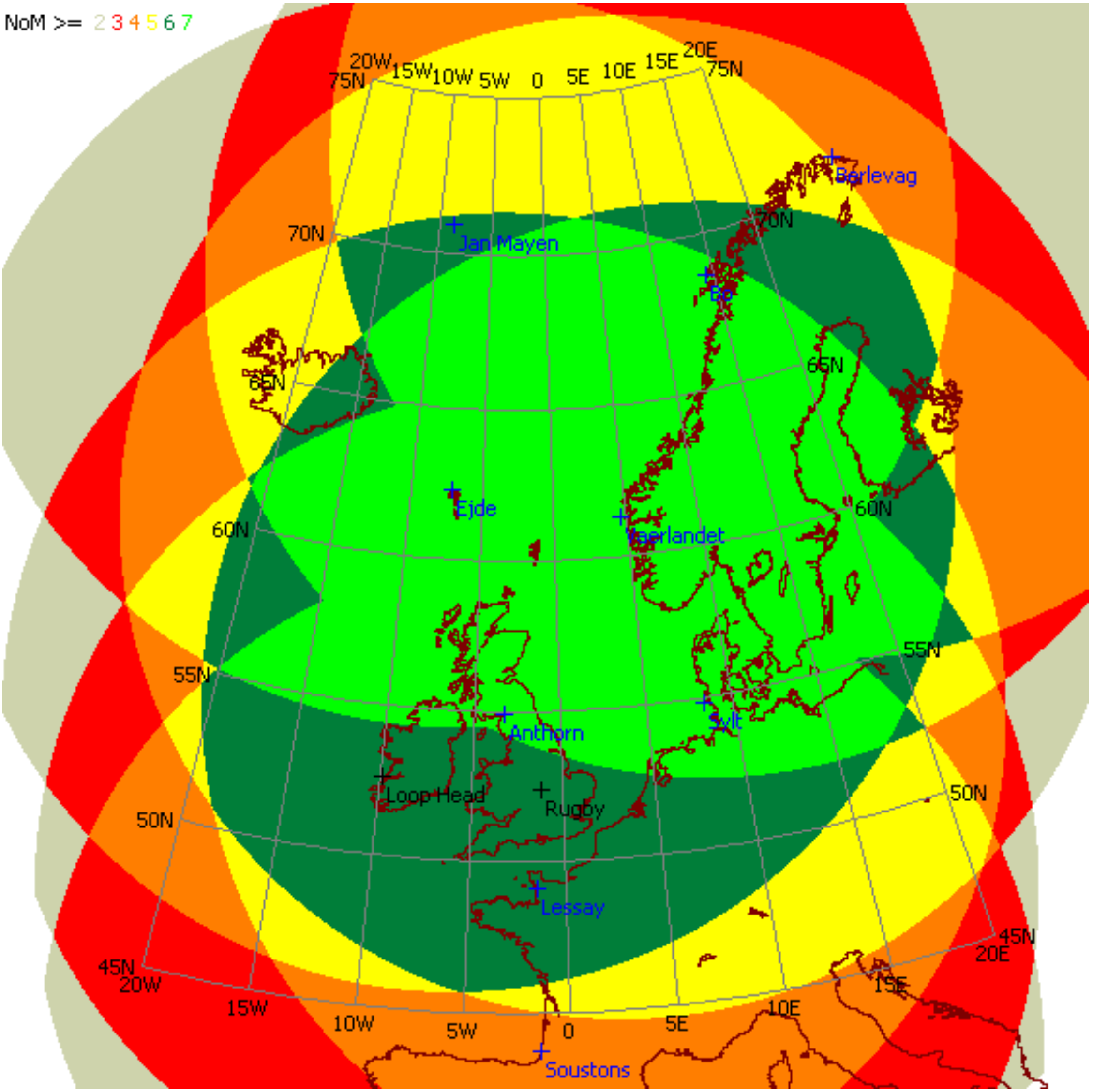
NW Europe : Loran Stations – Baseline : NoM



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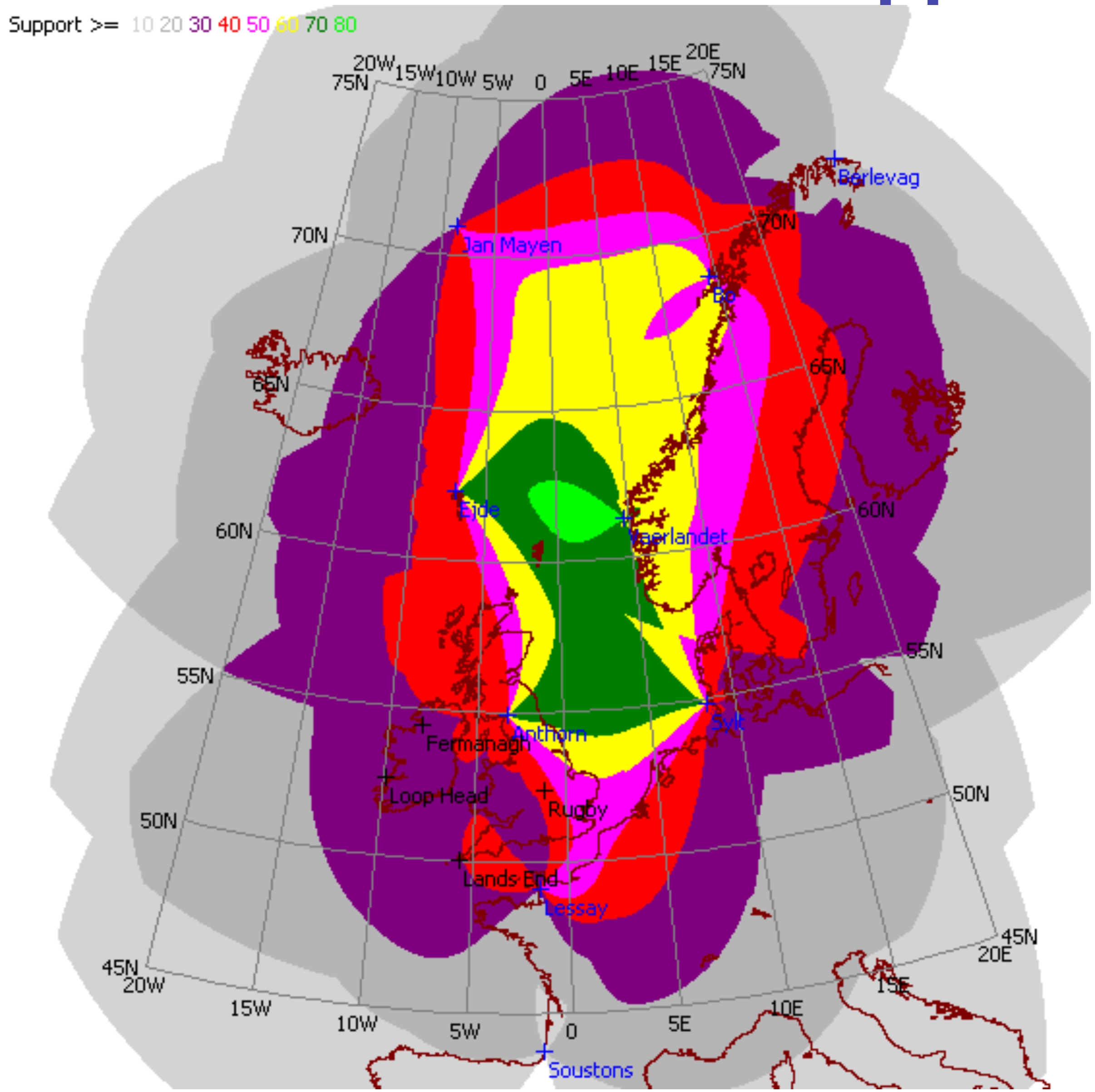
NW Europe Loran – Baseline : Support



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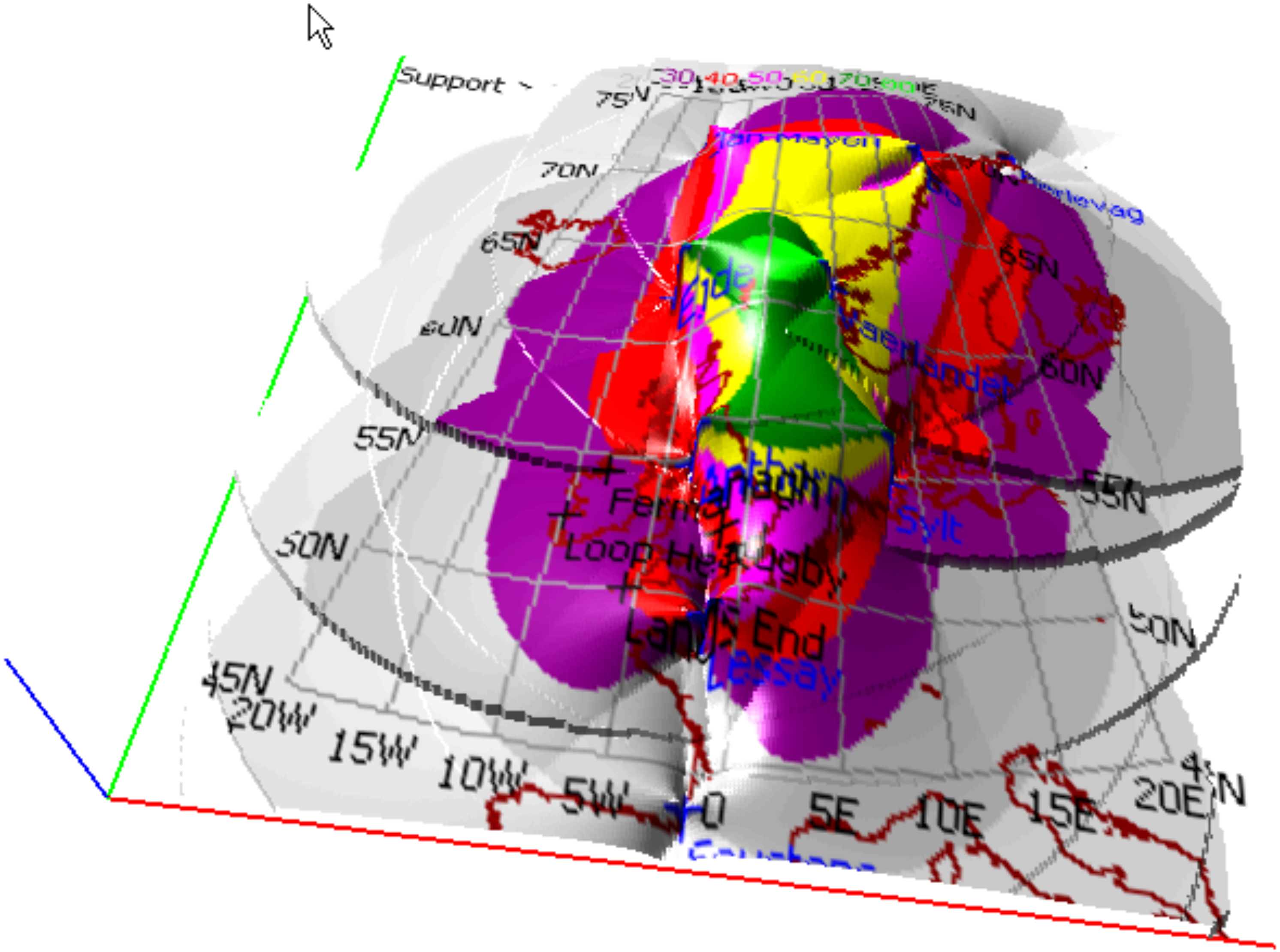
NW Europe Loran – Baseline : Support



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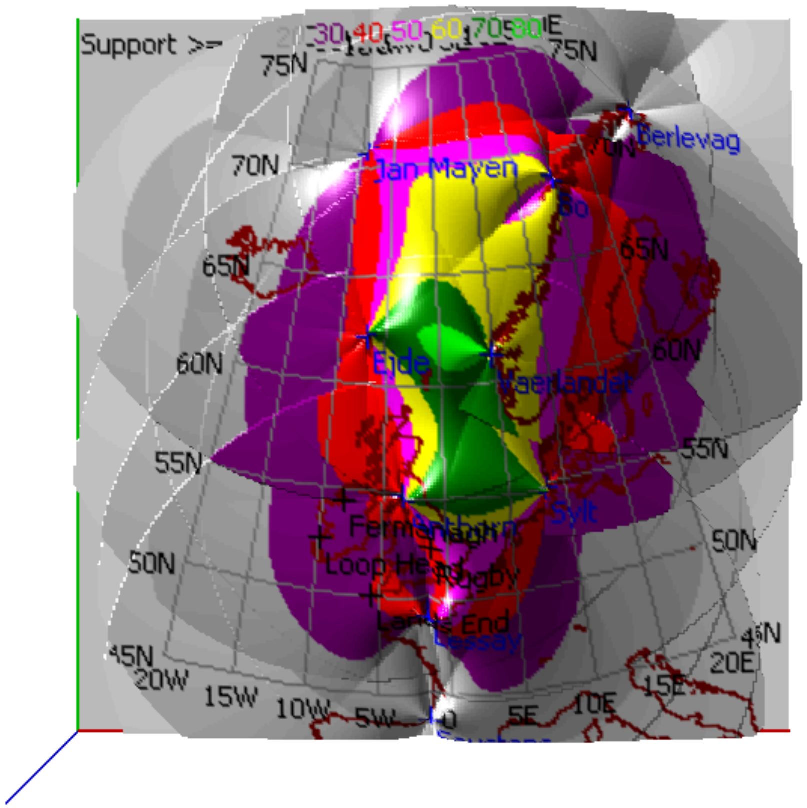
NW Europe Loran – Baseline : Support



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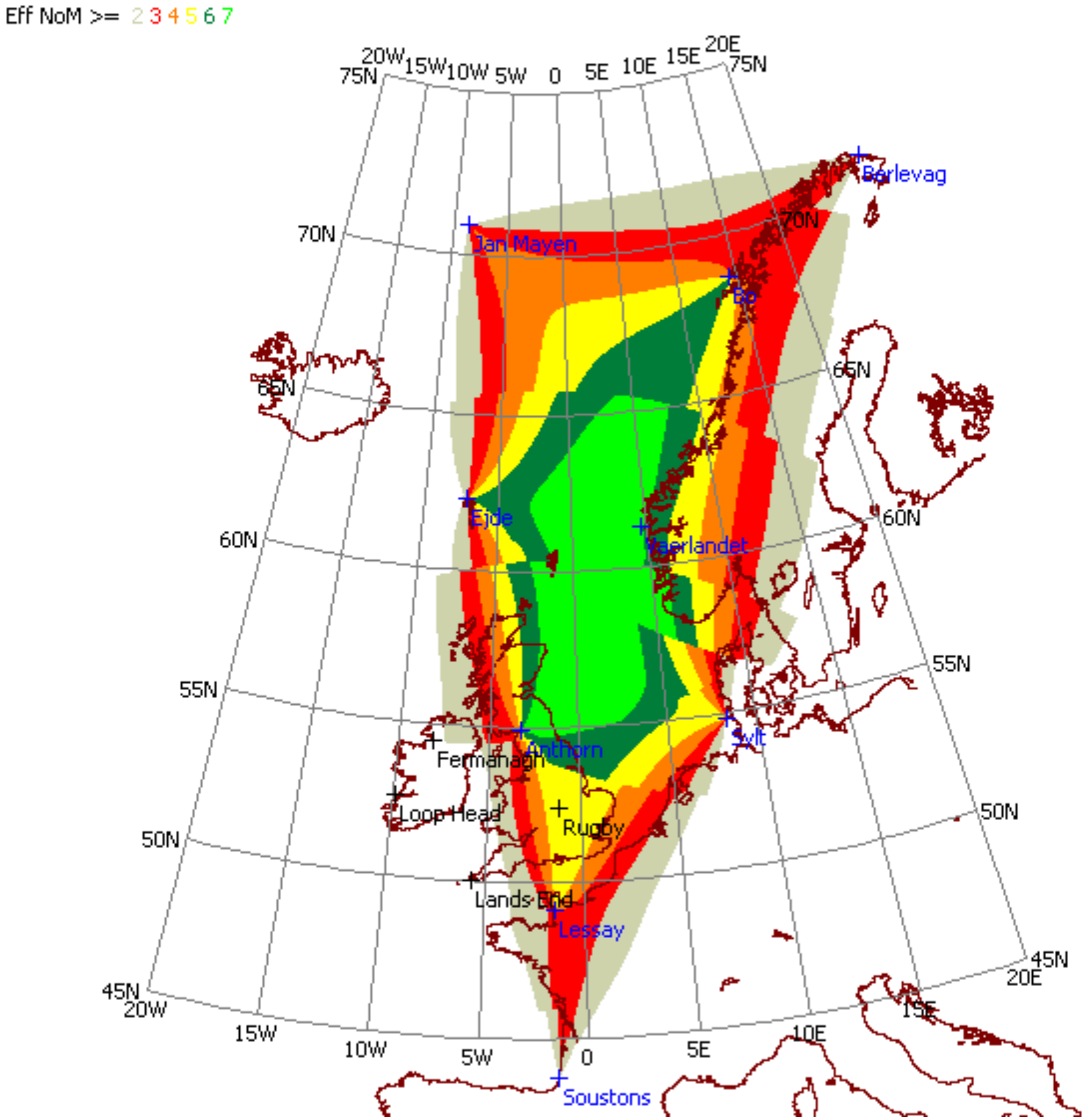
NW Europe Loran – Baseline : Neff



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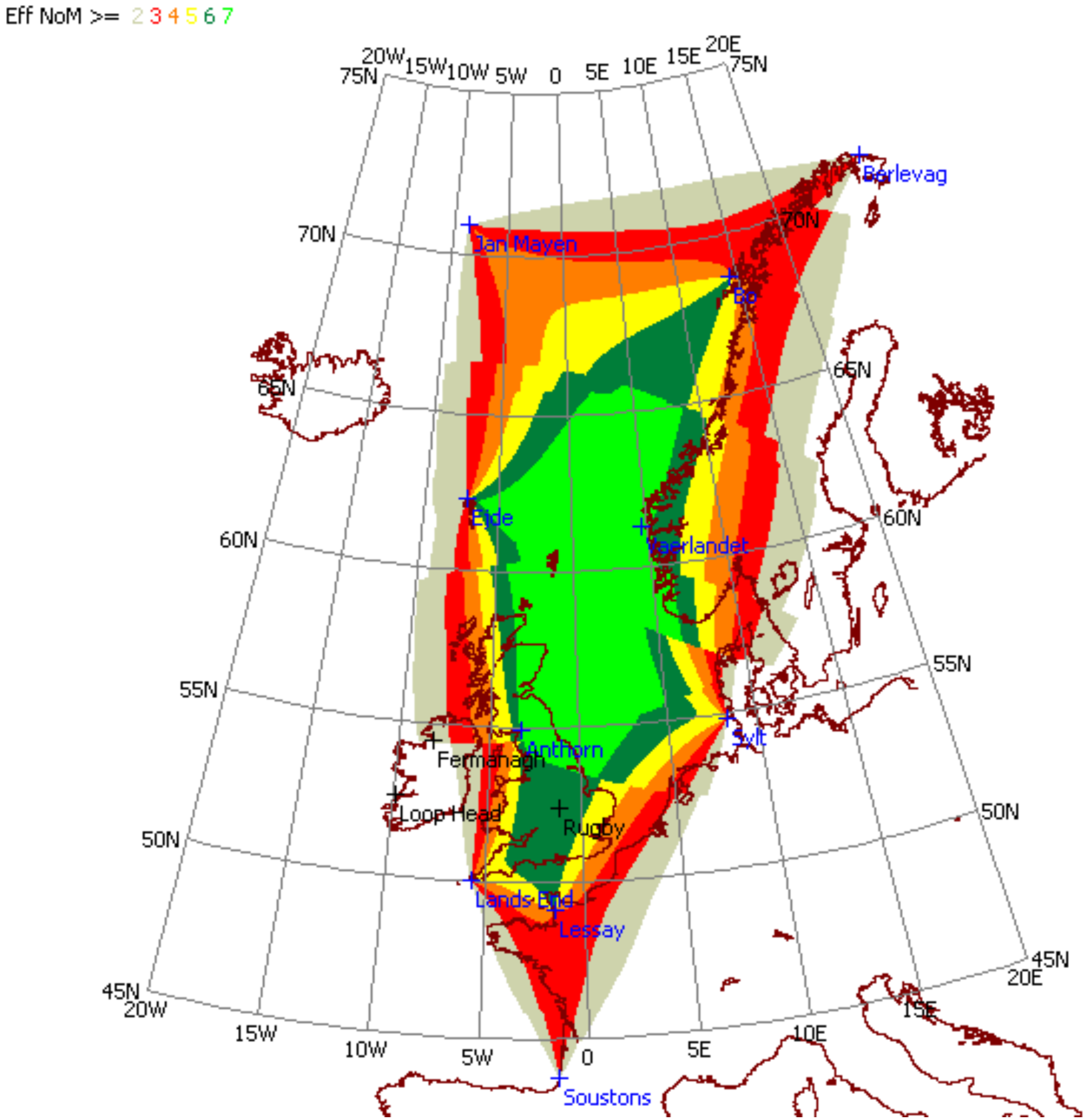
NW Europe Loran– Baseline + LE : Neff



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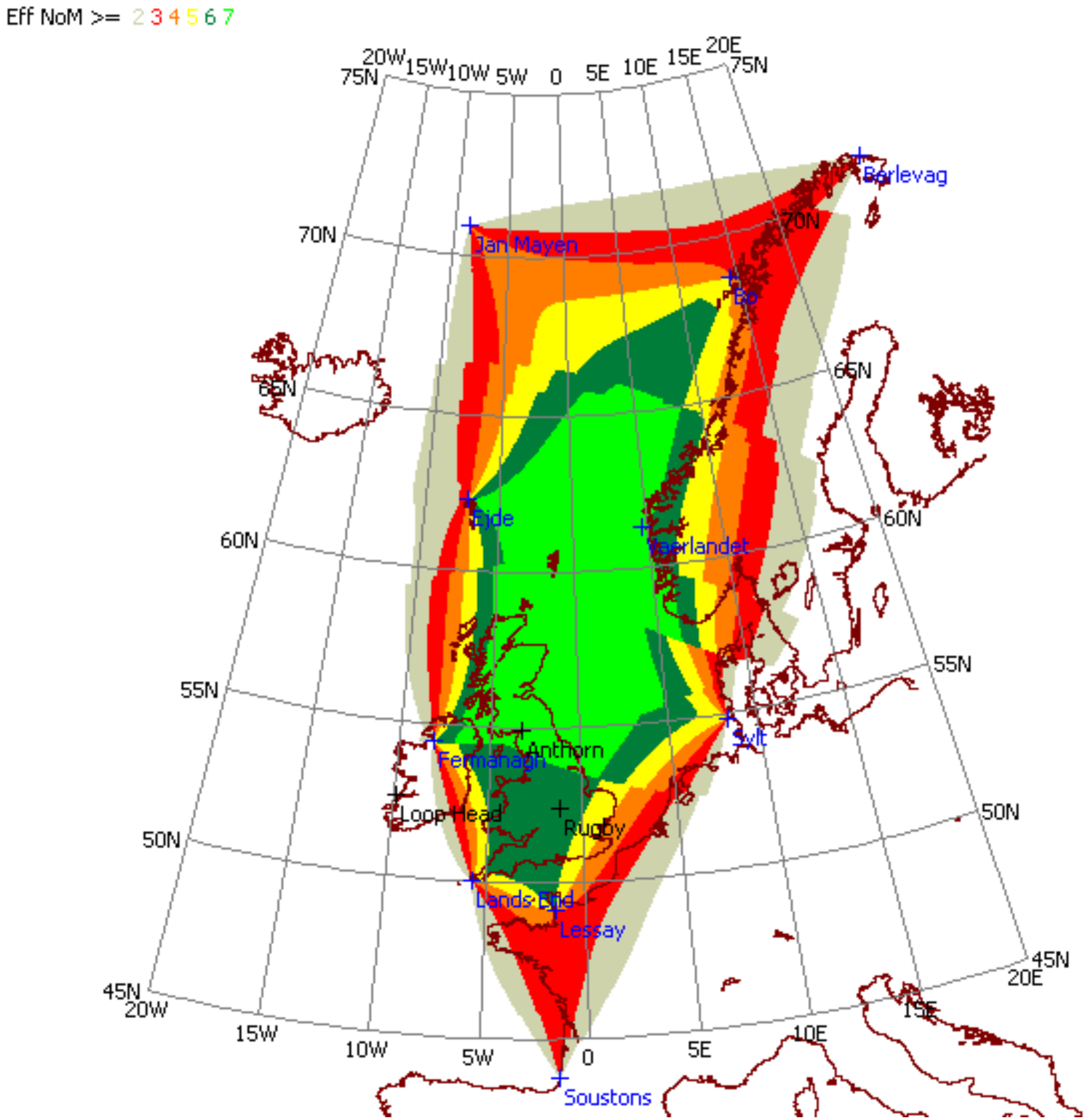
NW Europe Loran – A + F + LE : Neff



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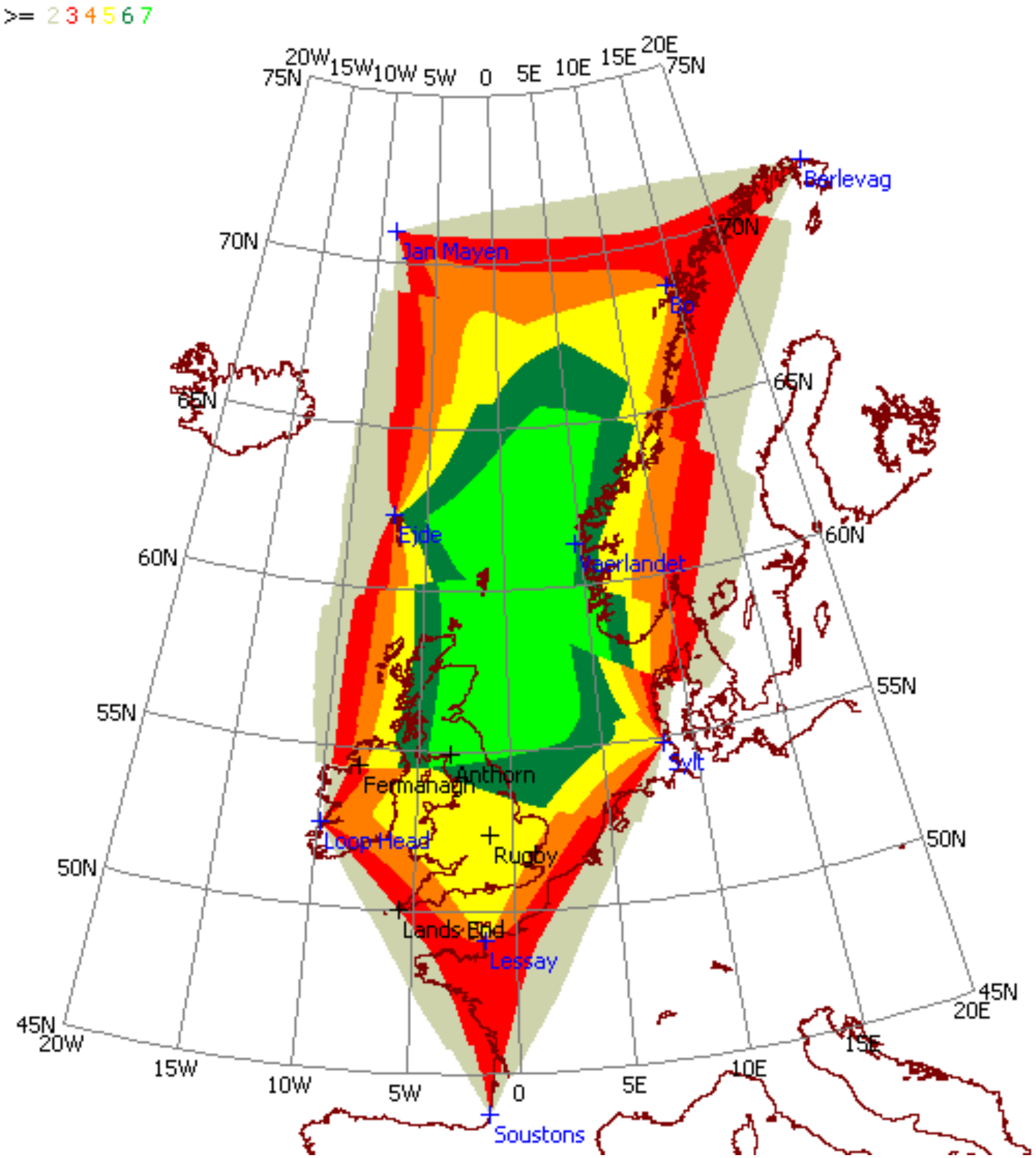
NW Europe Loran – A + LH : Neff



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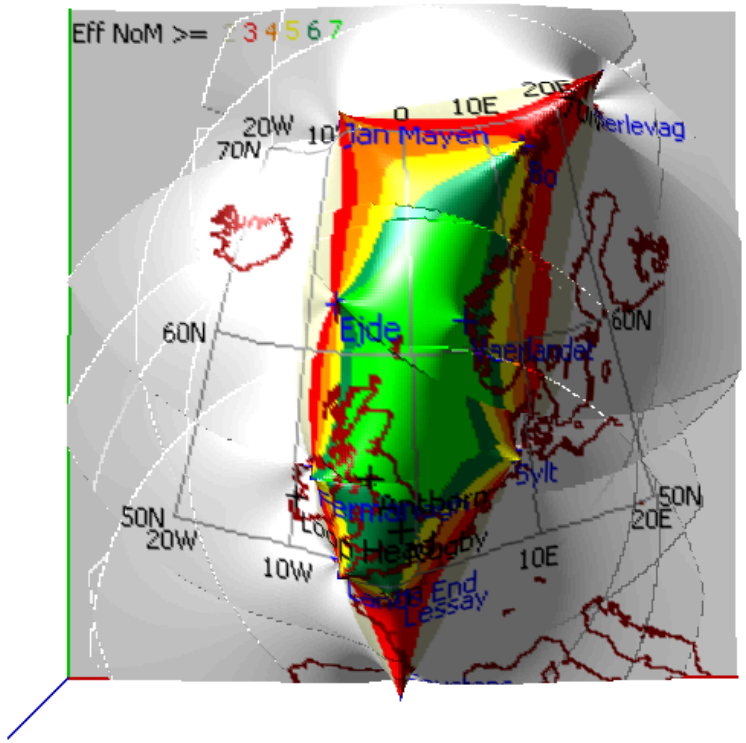
NW Europe Loran – A + F + LE : Neff



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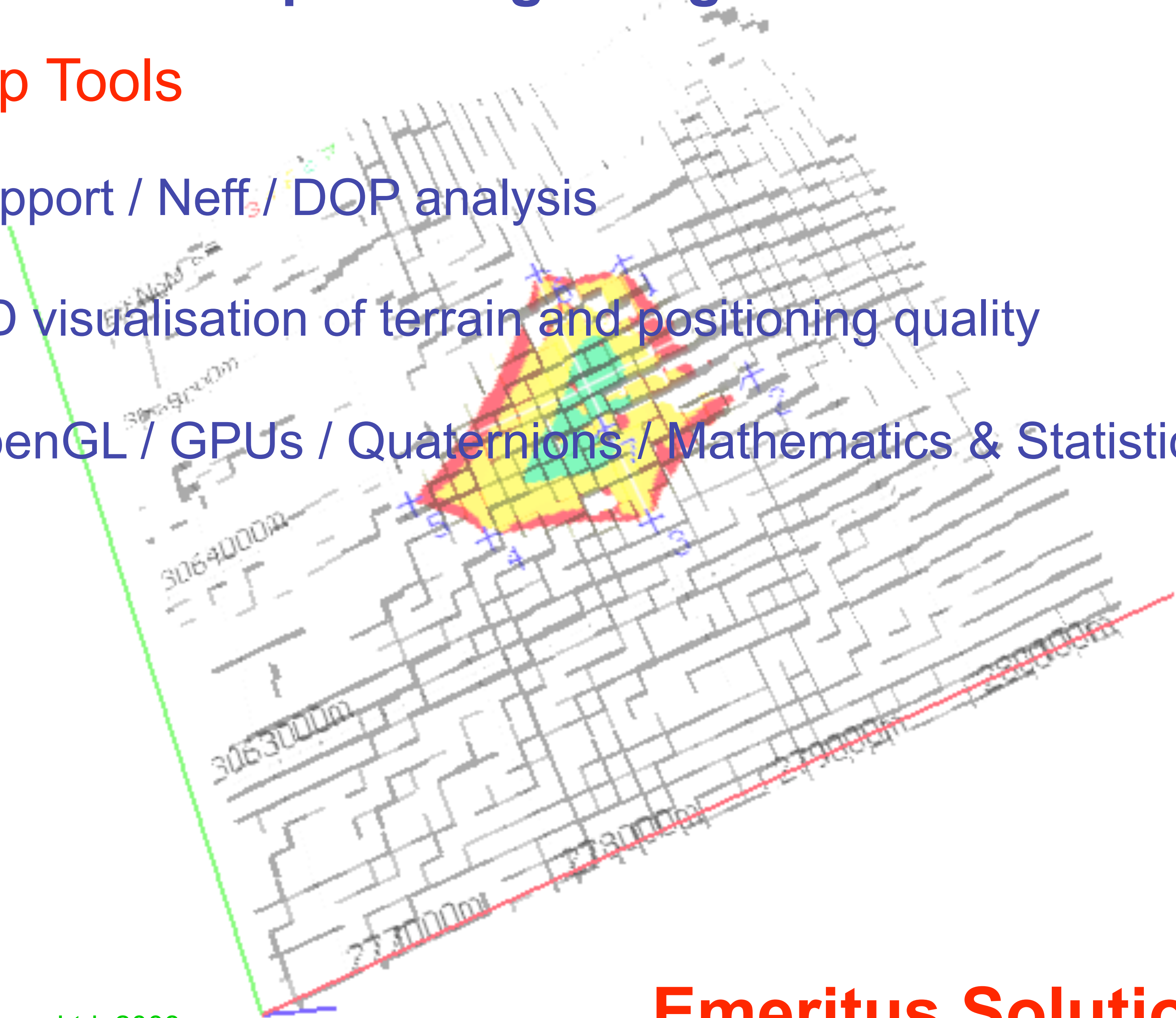
Sharp Tools for Optimising Navigation Sensor Arrays

- Sharp Tools
  - Support / Neff / DOP analysis
  - 3-D visualisation of terrain and positioning quality
  - OpenGL / GPUs / Quaternions / Mathematics & Statistics



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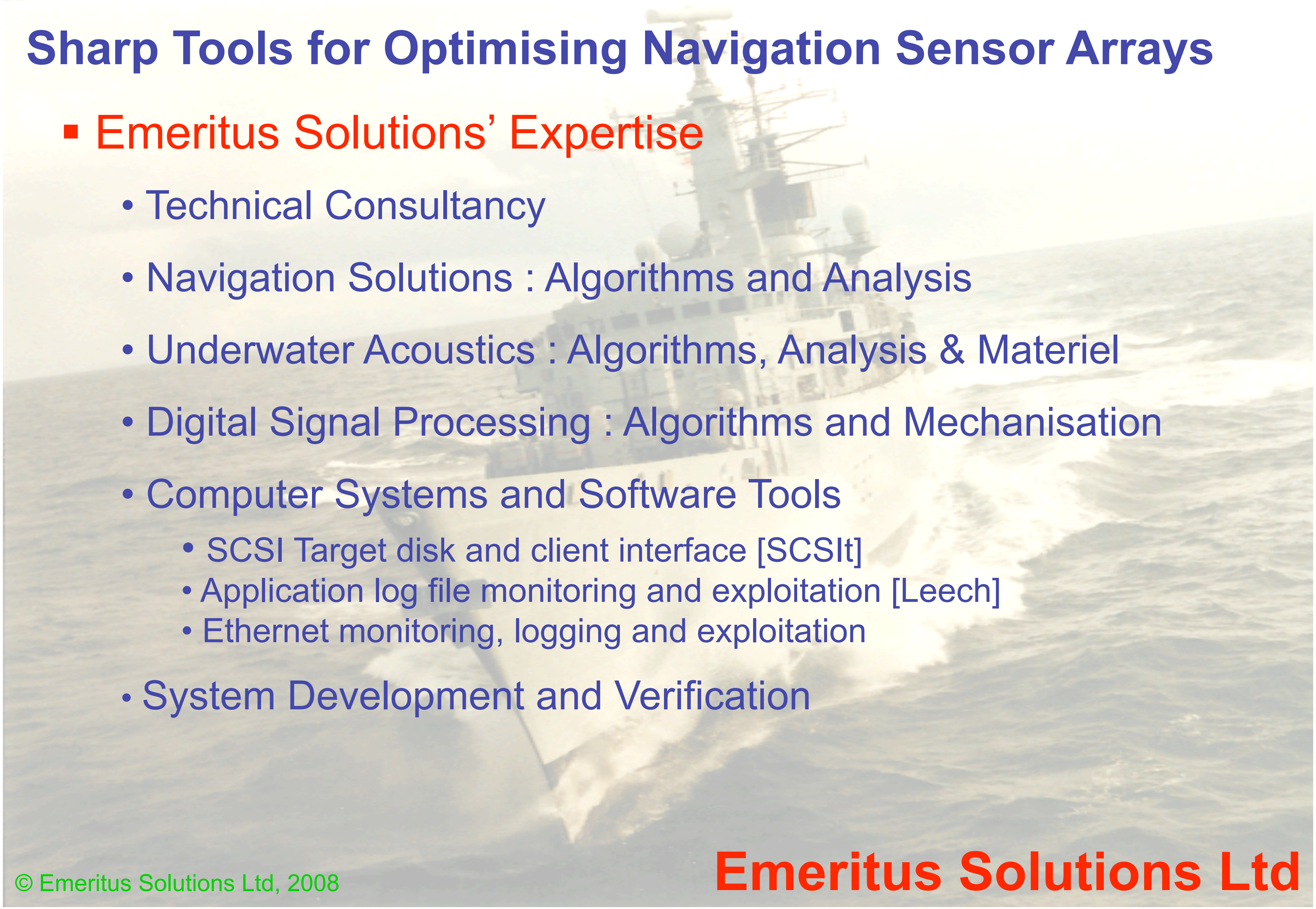

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  - Computer Systems and Software Tools
    - SCSI Target disk and client interface [SCSIt]
    - Application log file monitoring and exploitation [Leech]
    - Ethernet monitoring, logging and exploitation
  - System Development and Verification

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Technical Consultant

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