Changes since v3.4

- interpolation accuracy (surface/perturbation grid points)
- OPD calculation (chief ray, entrance/exit pupils, reference sphere)
- optical design files (data/lsst/optics_x.txt, more digits)
- n_silica (data/lsst/silica_dispersion.txt)
- monochromatic source (opdwavelength)
- radius of reference sphere (EPR)
- Zernike polynomials in Cartesian coordinates
- Zernike polynomials in Noll's nomenclature
- perturbation for fused surface
- importing Zemax grid data **[I]**
- interpolation near surface edge **[II]**
- sag derivatives **[III]**

I. Importing Zemax grid data

- PhoSim now supports irregular gridded FEA type of data or Zemax grid data.
- Command: `fea 0 (surface id) M1_b20_-0.50_grid.DAT`

FEA file format:

`x0 y0 z0 Tx Ty Tz  Rx Ry Rz`

original grid point position (mm), translation (mm), rotation (degree)

Zemax grid data file format (end in the extension .DAT):

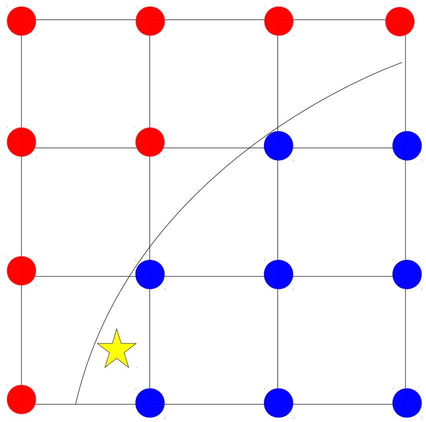
`nx ny delx dely`

`z dz/dx dz/dy d2z/dx/dy`

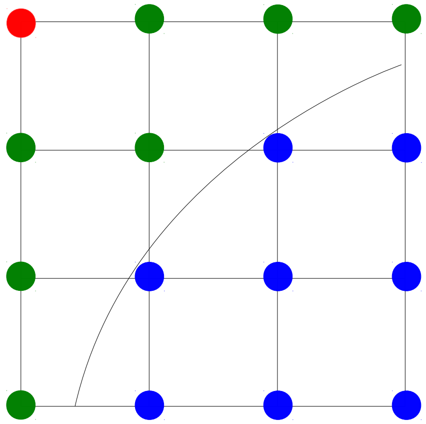
nx x ny regular grid points, separated by delx and dely (mm); z: additional sag (mm)

II. Interpolation near surface edge

- interpolation used in PhoSim: (1) regridding input perturbation data (e.g., mapping 200 x 200 data → 1024 x 1024 PhoSim grids) (2) looking up surface height from pre-calculated surface/perturbation data.
- (1): for every point on 1024x1024 grids, PhoSim finds nearest 4 input nodes and performs a planar regression (higher order fit possible) to determine the surface height. Need to exclude input nodes that are not on the surface in the fit (for Zemax grid data).
- (2): problems arise from changing spherical grids to Cartesian. There are grid points not on the surface (value 0).



Quick Fix:
extrapolating to $r > r_{outer}$ and $r < r_{inner}$, properly defining grid points near the edge

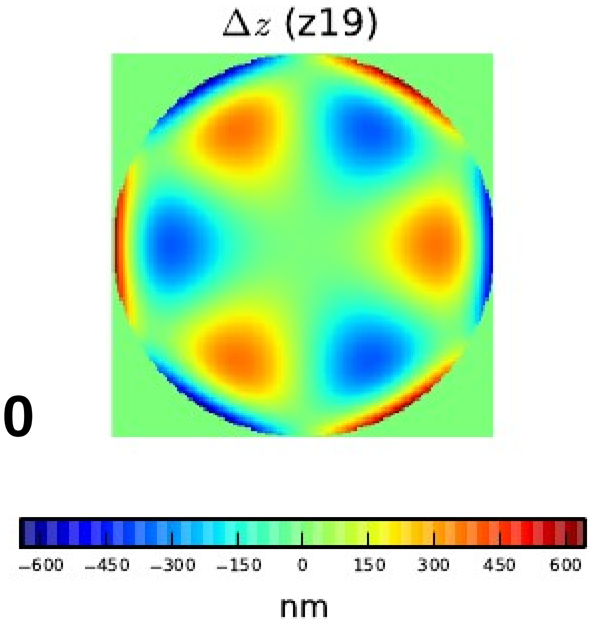


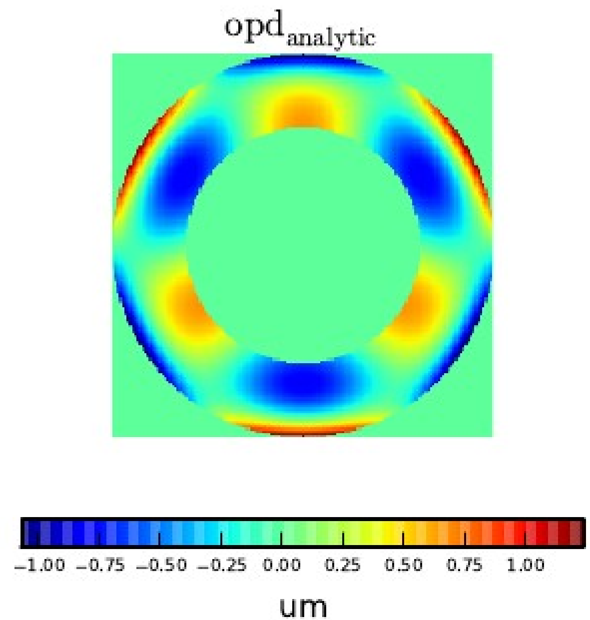
II. Interpolation near surface edge

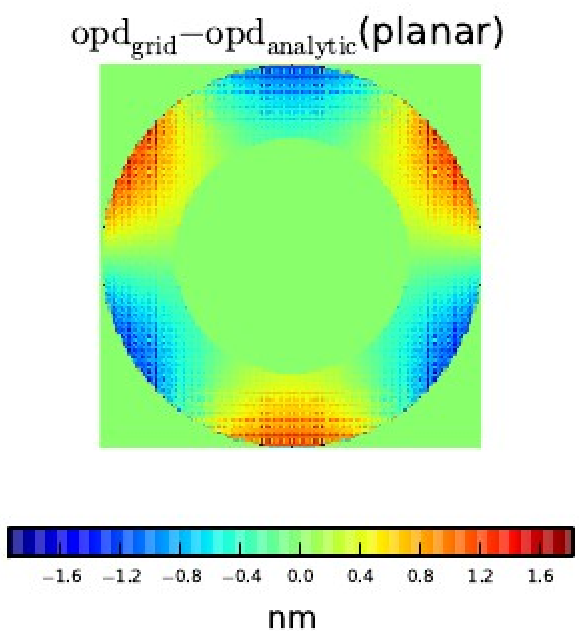
Test case:
0.2 um z19
perturbation on M1

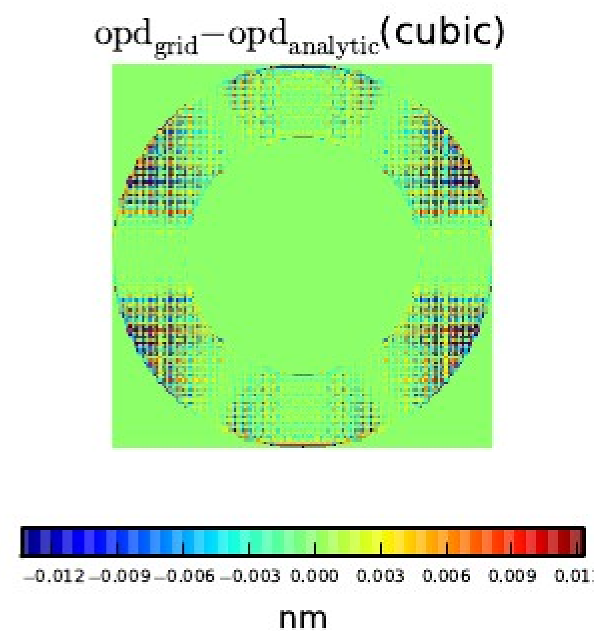
Comparing 200x200 z19 grid data against analytic perturbation

Max difference:
4.6 nm (4pt planar)
0.07 nm (10pt cubic)









III. Sag derivatives

- When regridding input perturbation data, PhoSim is solving linear equations of the dth degree polynomial fit to n nearest input nodes.

$$\mathbf{z} = \mathbf{A}\,\mathbf{b},$$

where

$$\mathbf{z} = \begin{pmatrix} z_1 \\ z_2 \\ \vdots \\ z_n \end{pmatrix},$$

z: surface perturbation
b: coefficients of the dth degree polynomial.

$$\mathbf{A} = \begin{pmatrix} 1 & x_1 & y_1 & {x_1}^2 & x_1\,y_1 & \cdots & {y_1}^d \\ 1 & x_2 & y_2 & {x_2}^2 & x_2\,y_2 & \cdots & {y_2}^d \\ \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & x_n & y_n & {x_n}^n & x_n\,y_n & \cdots & {y_n}^d \end{pmatrix},$$

- sag derivatives provide additional constraints to the equations: ∂z/∂x = ∂A/∂x b, ∂z/∂y = ∂A/∂y b, which are linear equations, too.
- Currently we only consider first derivatives.