The Influence of Spatial Energy Distribution on Cover Performance

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Dry Cover Design Tools

- Models to predict the water balance considering the impact of climate and soil type
- Some common models:
  - HELP
  - SWIMM
  - Hydrus, Hydrus-2D
  - SoilCover, Vadose/W

Model limitations

- All models simplify real-world conditions
- Main difference in models lies in what assumptions are made
- Evolution of modeling has lead to more sophisticated calculations.
- Example: SoilCover
  - Introduced calculation of actual evaporation
  - solution of heat and mass flow equations
  - coupled with climate and soil data

Moving Beyond 1D

- 1 D is the most basic case to model, and provides great deal of design information
- Real world processes vary in 3D, and cover design research is progressing in this direction
  - Aubertin, Brussiere et al. (Sloped Capillary Barriers)
  - Vadose/W (2D formulation of SoilCover)
  - O'Kane et al.

The need for a 3D approach

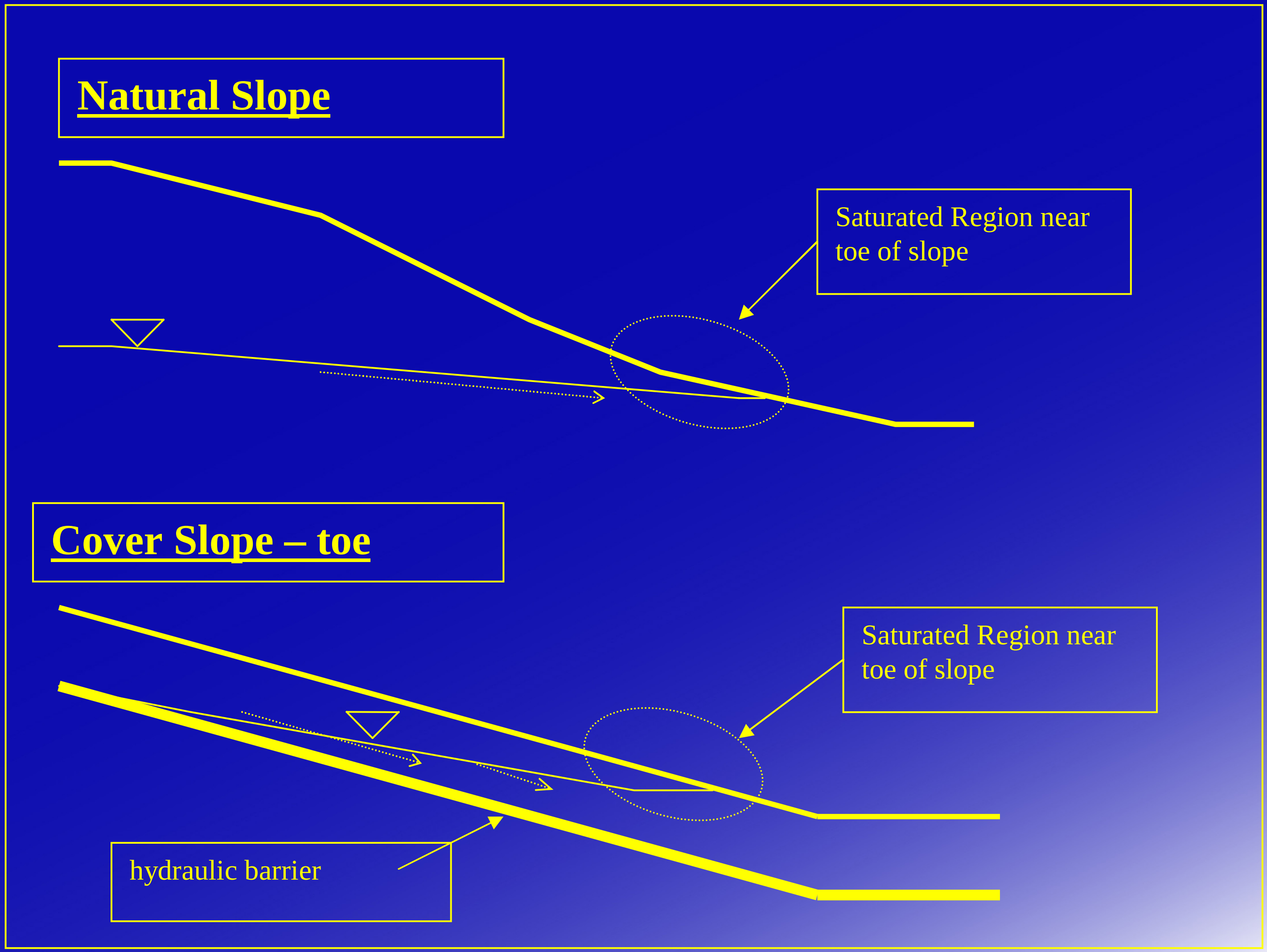
- Waste dumps frequently have large above-grade portions, with sloped surfaces.
- Depending on the site configuration, sloped surfaces can make up the majority of the dump.
- Slopes on waste rock dumps are typically steep, 2.5H:1V

Sloped Cover at Equity Silver (BC)

Some Factors that may vary with slope:

- Net Radiation (especially solar) – affects evaporation
- Moisture Distribution – higher near toe

Moisture at toe of slope



Some Factors that may vary with slope:

- Net Radiation (especially solar) – affects evaporation
- Moisture Distribution – higher near toe
- Runoff Rates – may vary with slope
- Wind – local variations can affect evaporation and snowpack
- *Vegetation – differences induced by these other factors*

Importance of Net Radiation

- Evaporation is a major water sink at many sites
- Evaporation is driven by net radiation (Q_{net})
- Q_{net} is strongly influenced by the slope and aspect of a soil cover

- “ …variability in elevation, slope angle and and orientation . . . can create strong local gradients in solar radiation”
  - O. Antonic, 1998, Ecological Modelling

- “The radiation received by a surface is usually the major determinant of its climate”
  - T.R. Oke, 1987, Boundary Layer Climates

Net Radiation (Q_{net}) and Actual Evaporation

- Both AE and PE are partly functions of net solar radiation

$$AE = \frac{\Gamma Q_{net} + \nu E_a}{\Gamma + A\nu}$$

Q_{net} is often measured as part of the climate monitoring at weather stations

The measurement of Q_{net} at a weather station

Net Radiometers

http://www.mining.ubc.ca

Evaporation in 3D

- The impact of 3D variations in net radiation have not been addressed in the context of cover design
- Previous attempts to look at this in a geotech context have not included actual evaporation calculations, or evaluated all aspects of radiation
- A model for the prediction of Q_{net} on slopes was required for use with existing flux boundary models.

The Components of Q_{net}

- Q_{net} is a composite measurement that includes several different types of radiation
- $Q_{net} = (S_b + S_d)_{down} + L_{up} - L_{down} - (S_b + S_d)_{up}$
  - S_b = beam component of shortwave
  - S_d = diffuse component of shortwave
  - L_{down}, L_{up} = the downwards and upwards components of longwave radiation

Radiation on a Slope

- Different components of Q_{net} are affected by slope/aspect to different degrees
  - S_b is most sensitive
  - S_d and longwave components are also sensitive but to a much lesser degree
  - This complicates prediction

Predicting Q_{net} on a Slope

- Developed a model to predict Q_{net} on the slopes of a given site, based on the Q_{net} measured over the horizontal area
  - Estimate each component of Q_{net} based on site-specific data.
  - Calculate effect of slope on each components
  - Sum the modified components to obtain Q_{net} on the slope

Model Requirements

- Inputs:
  - Q_{net}, Temp, humidity, site geometry, altitude, latitude, vegetation (albedo)
- Output
  - $Q_{net\ slope}$ for any given slope at the site

Model Verification – Using Field Data

- 90 days of field data collected on sloped soil cover (Equity Mine Site – North Central BC)
- Data collected on slopes facing all cardinal compass directions
- Slopes varied from 11 to 25 degrees.
- All slopes had similar vegetation, for similar albedo and emissivity.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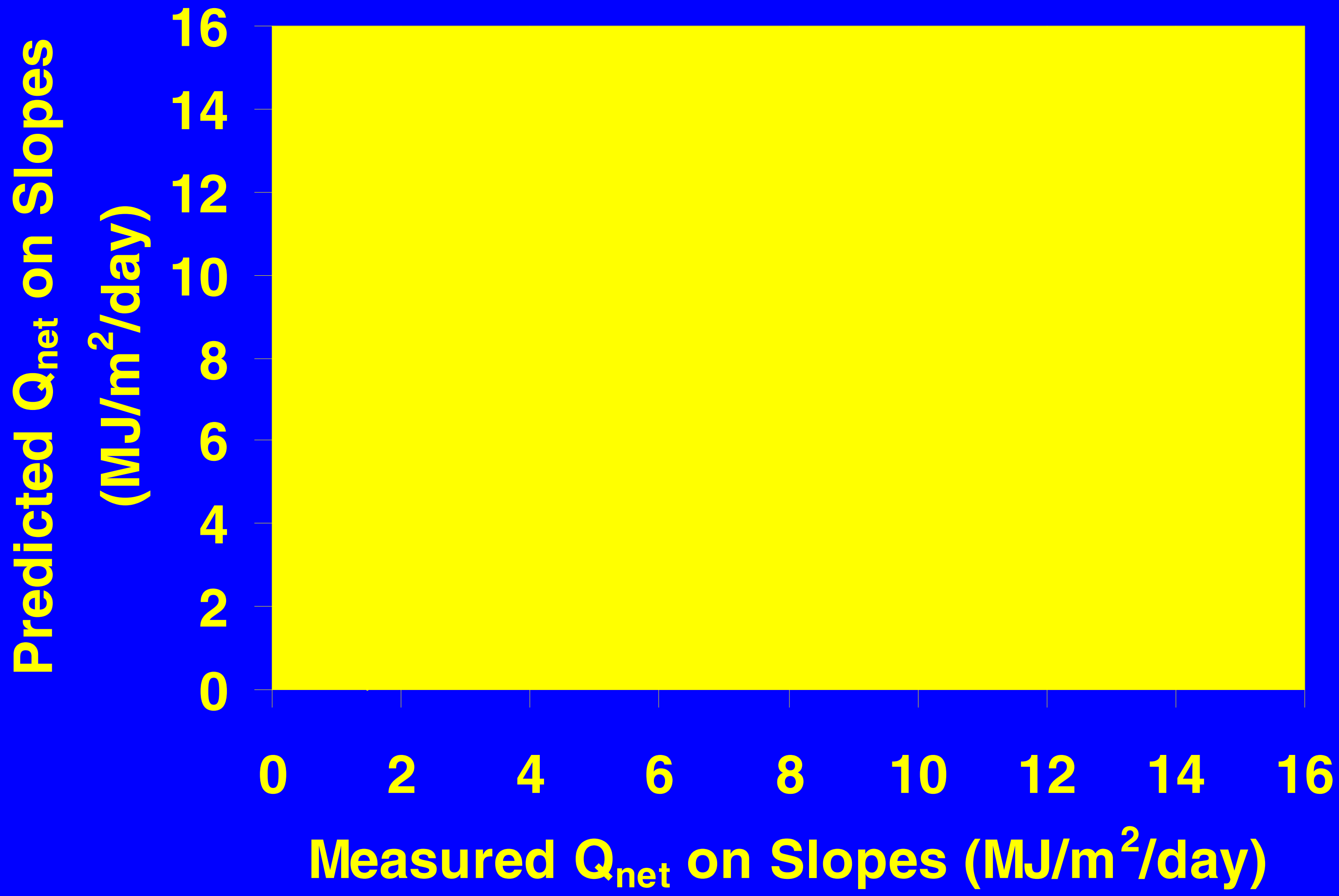
Q_{net} measurement on slopes

Measured-Predicted Q_{net}

(R^2=0.95)



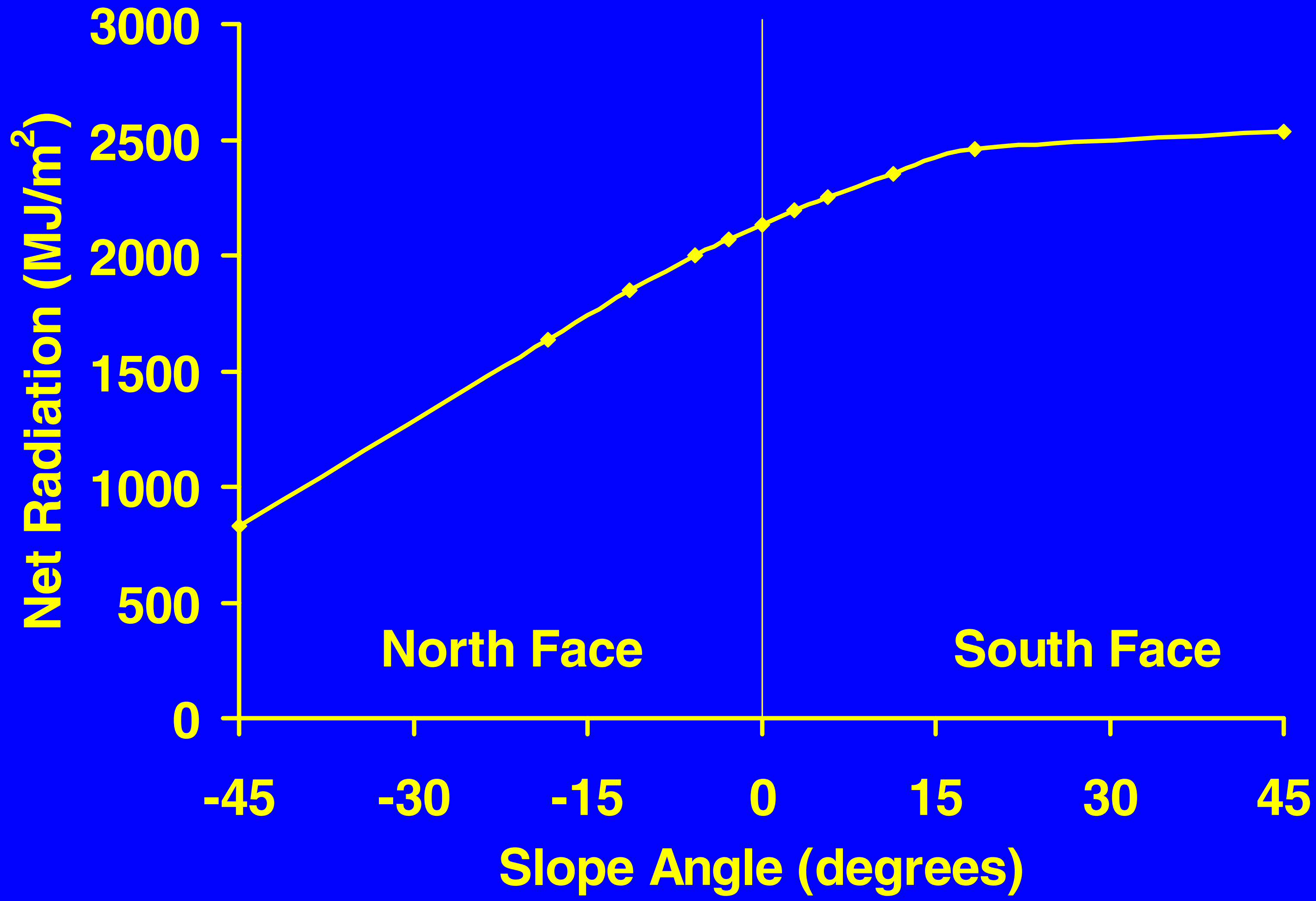
Verification

- Verification showed satisfactory performance of model
- Statistical analysis showed that model performed well on a variety of slopes.
- Now have confidence to apply model to site

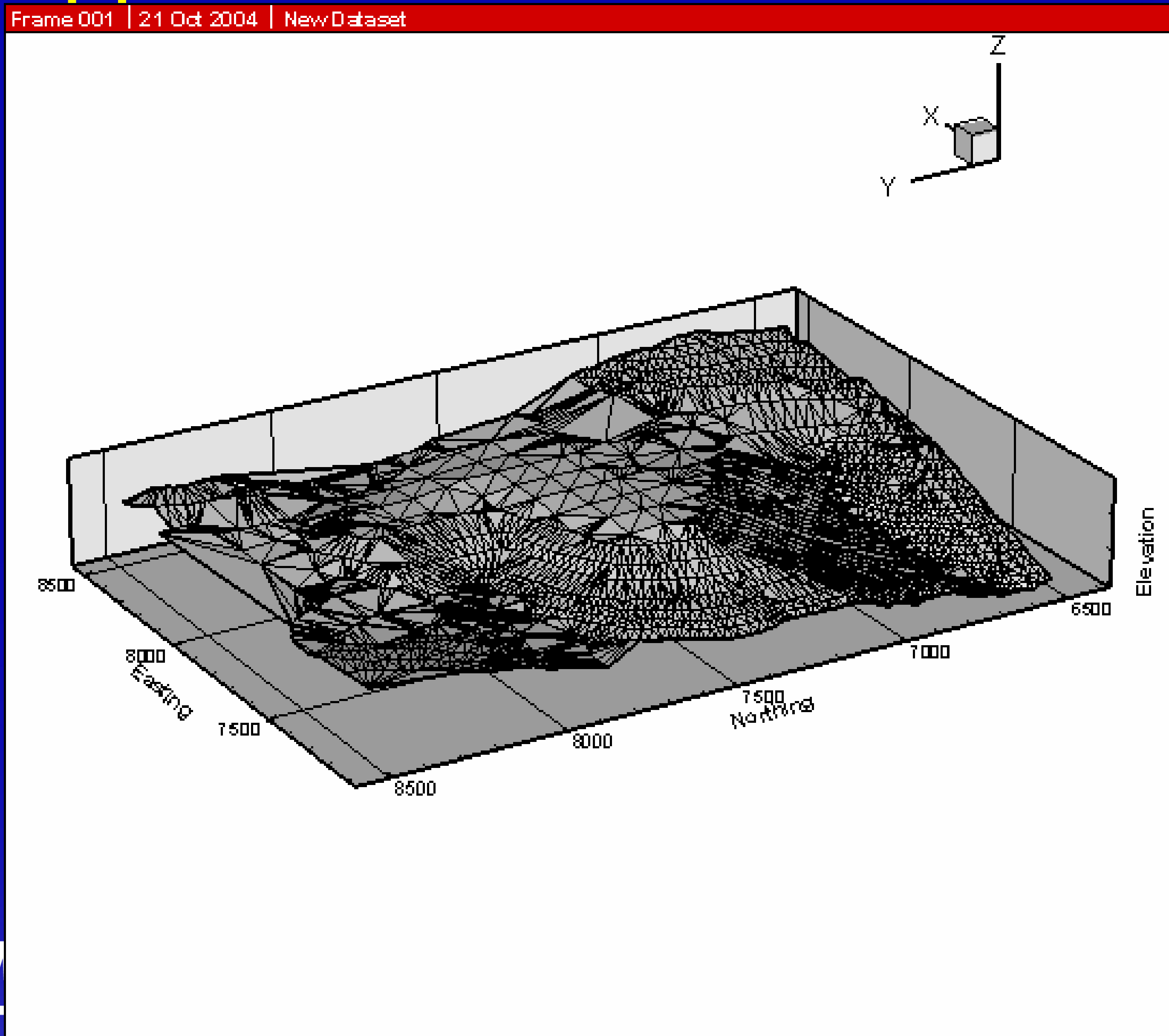
Model Application

- With predictive model for net radiation we can:
  - Predict how Q_{net} varies as a function of slope
  - Map the variations in Q_{net}
  - Couple these predictions with climate data to predict variations in PE
  - Couple with soils data to predict variations in AE (using existing models)

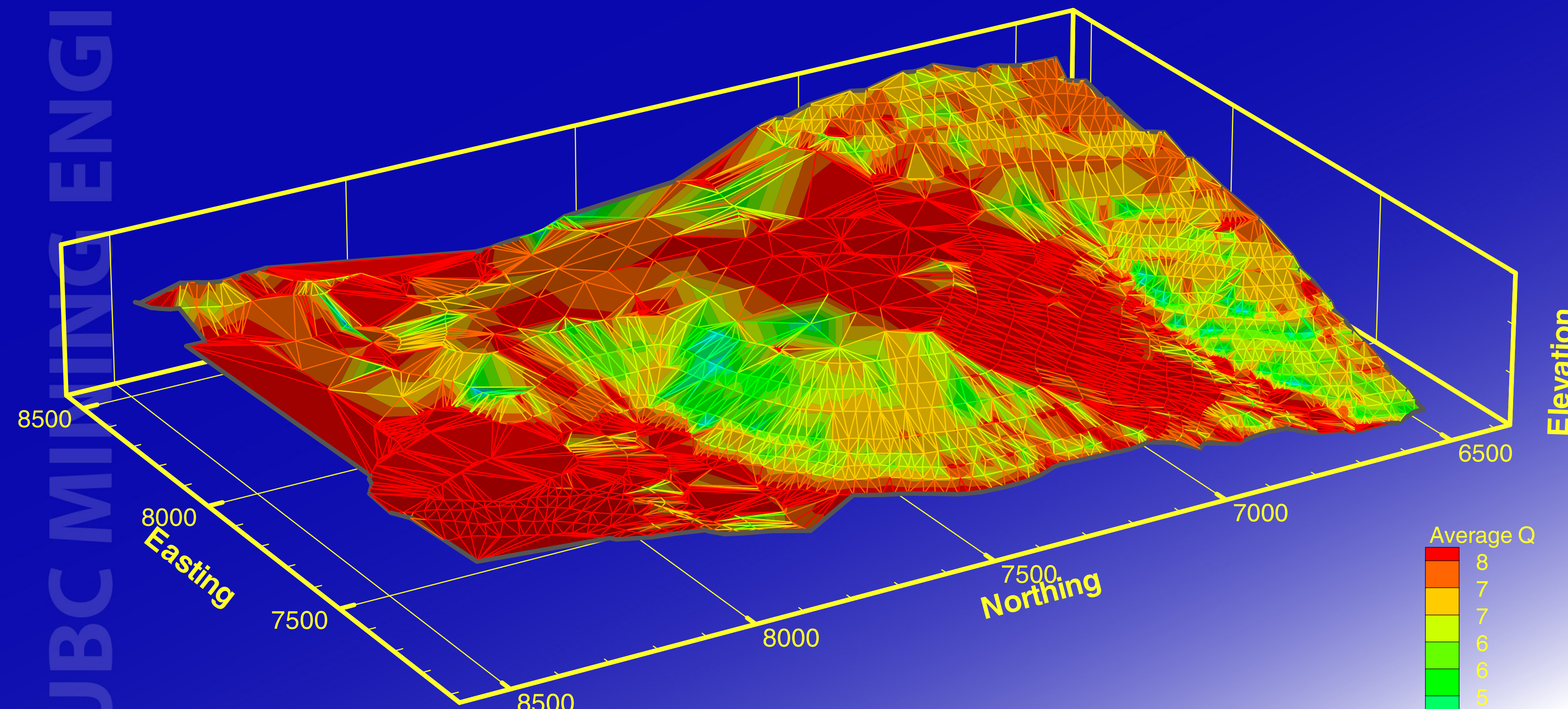
Impact of Slope on Annual Net Radiation



Application In 3D – Site Mesh



Annual Average Q_{net}



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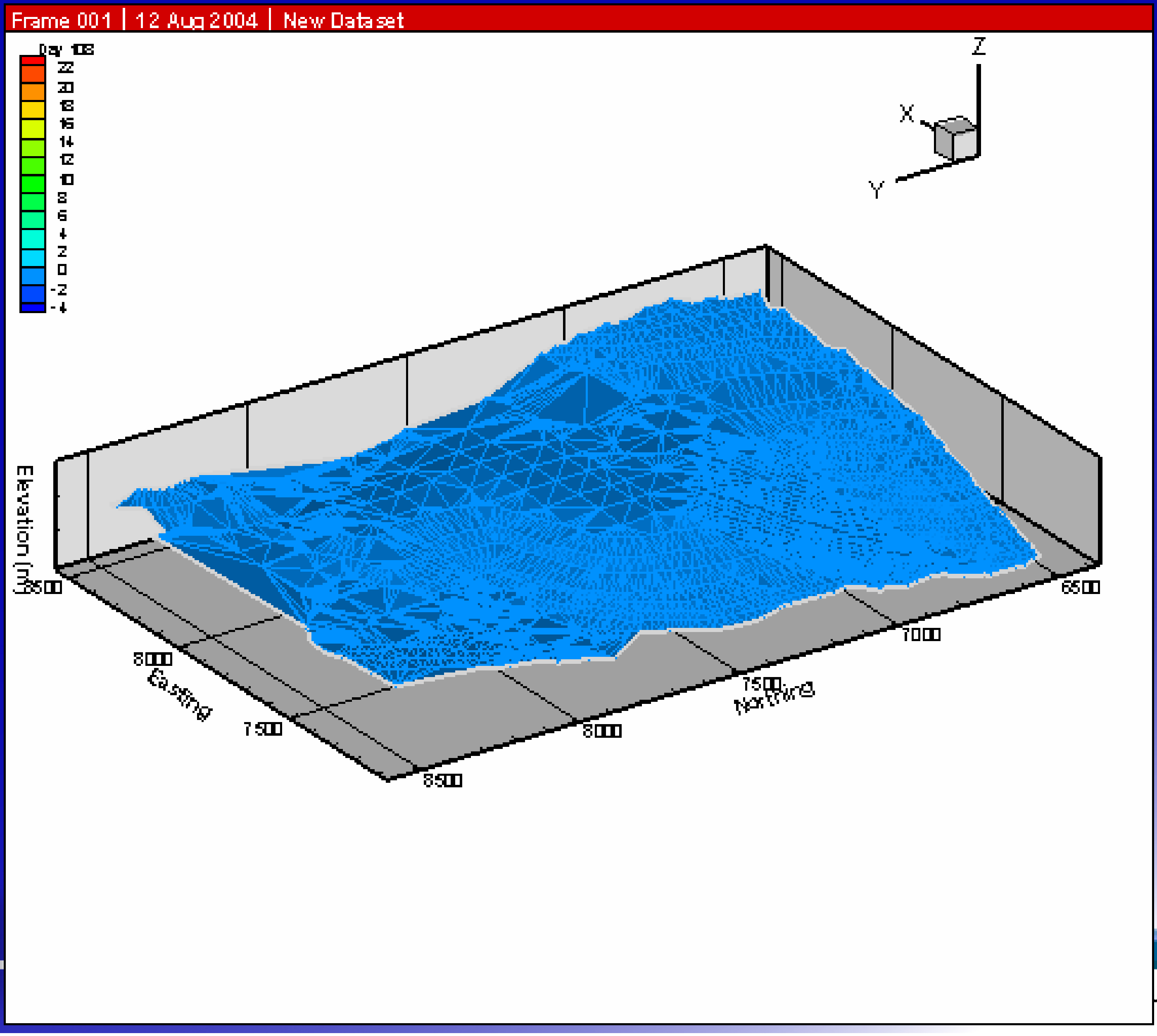
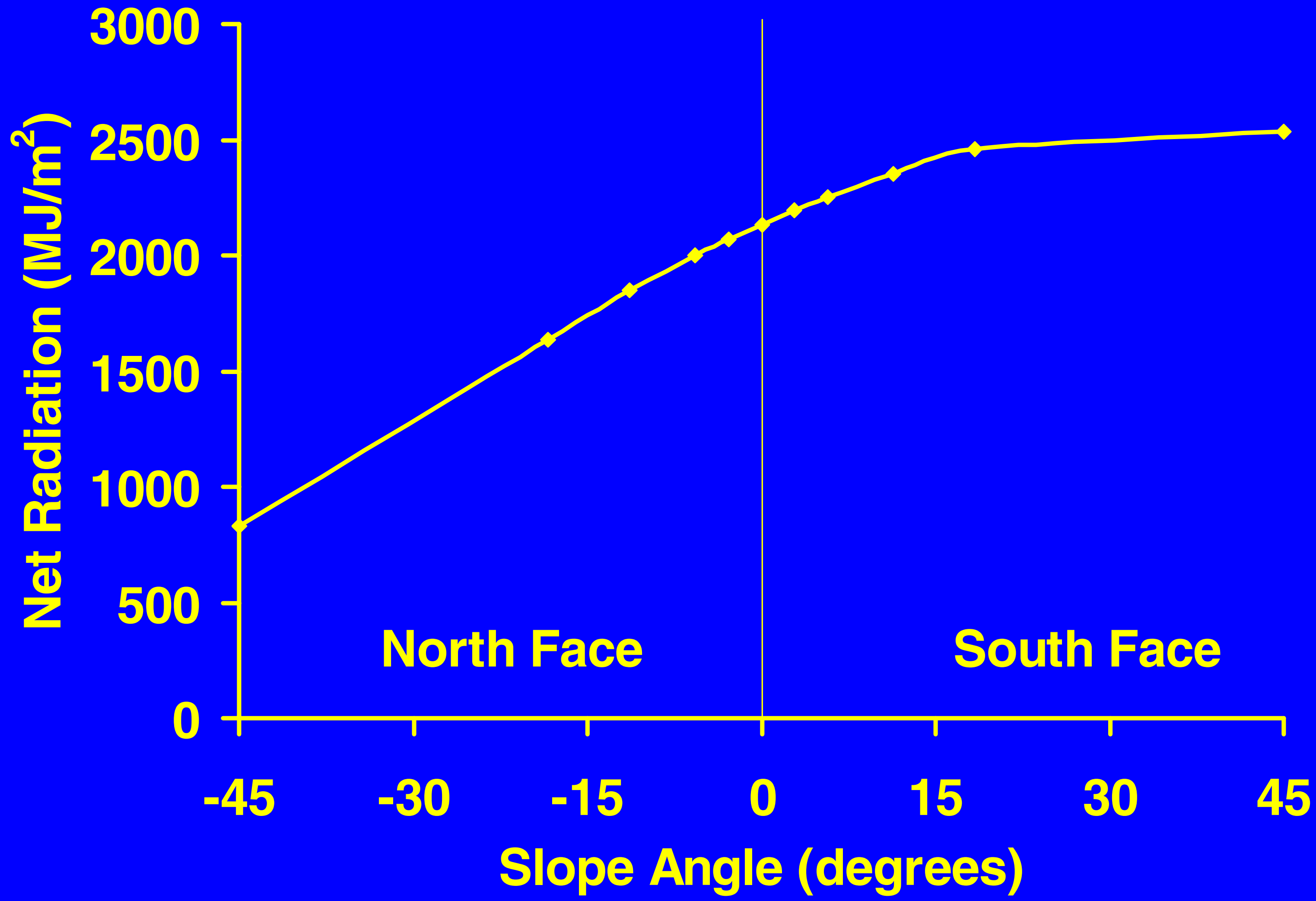
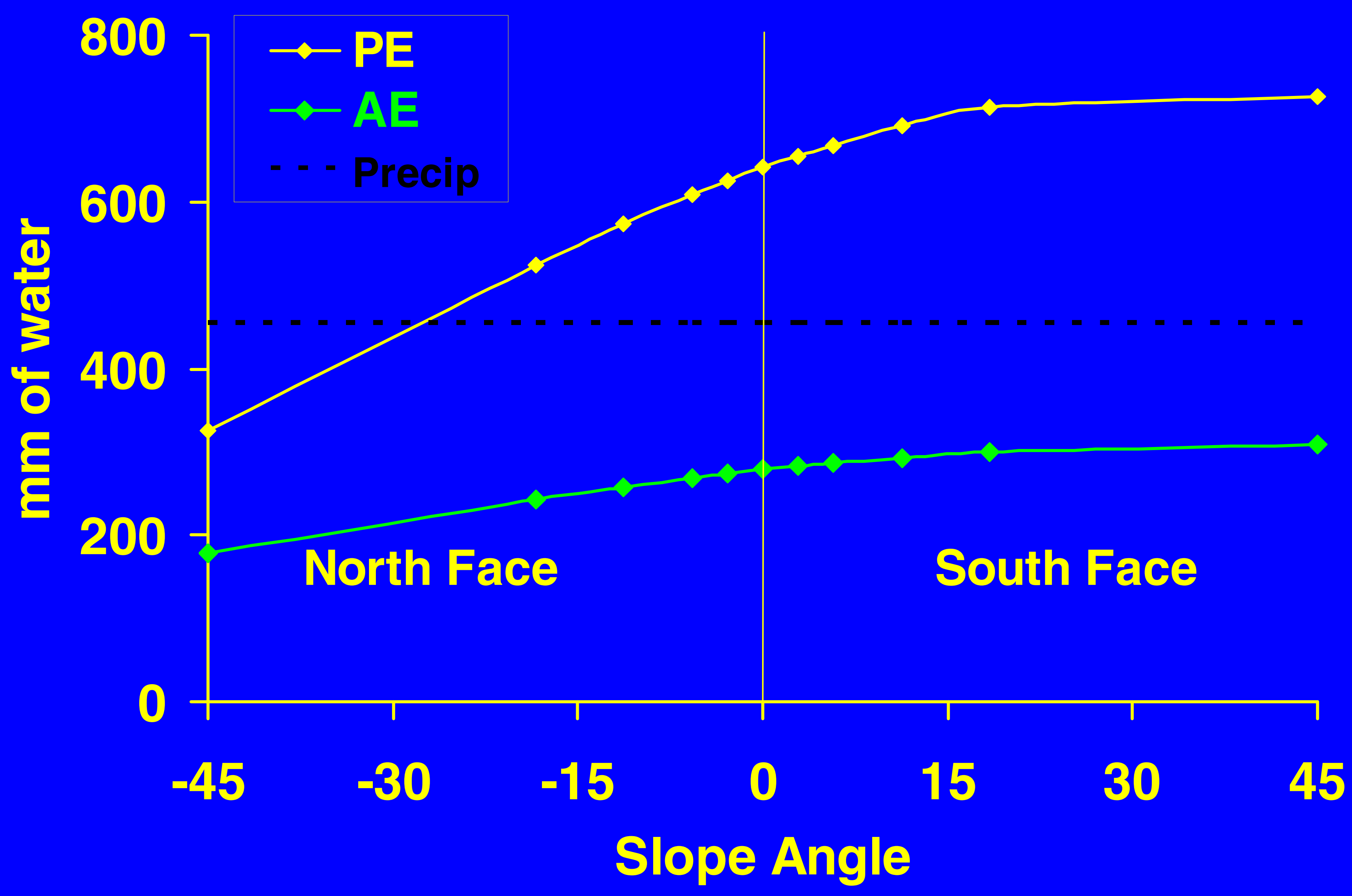
Variation of Q_{net} over Time



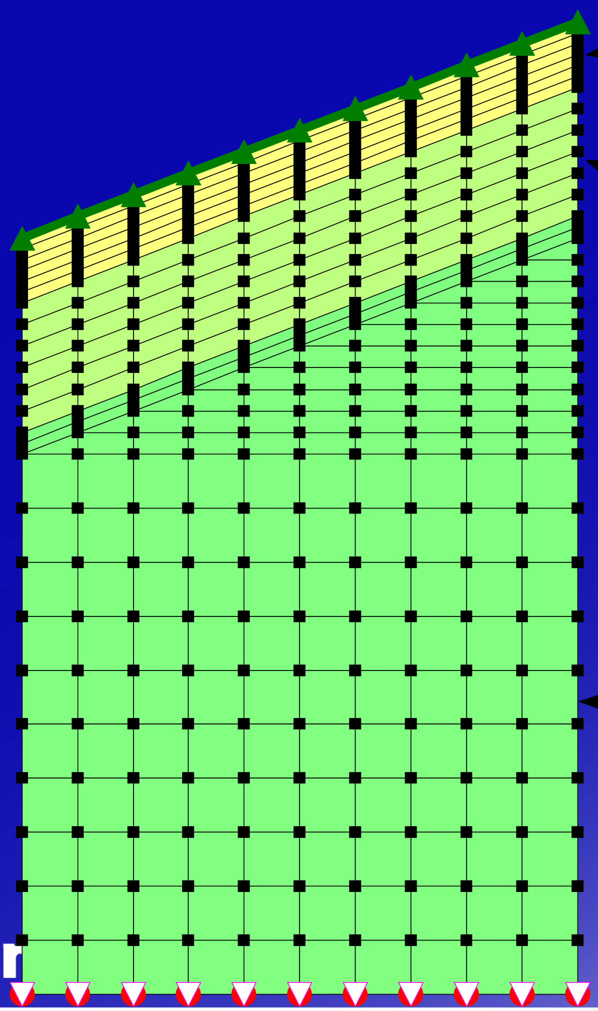
Slope effect on radiation compared to…



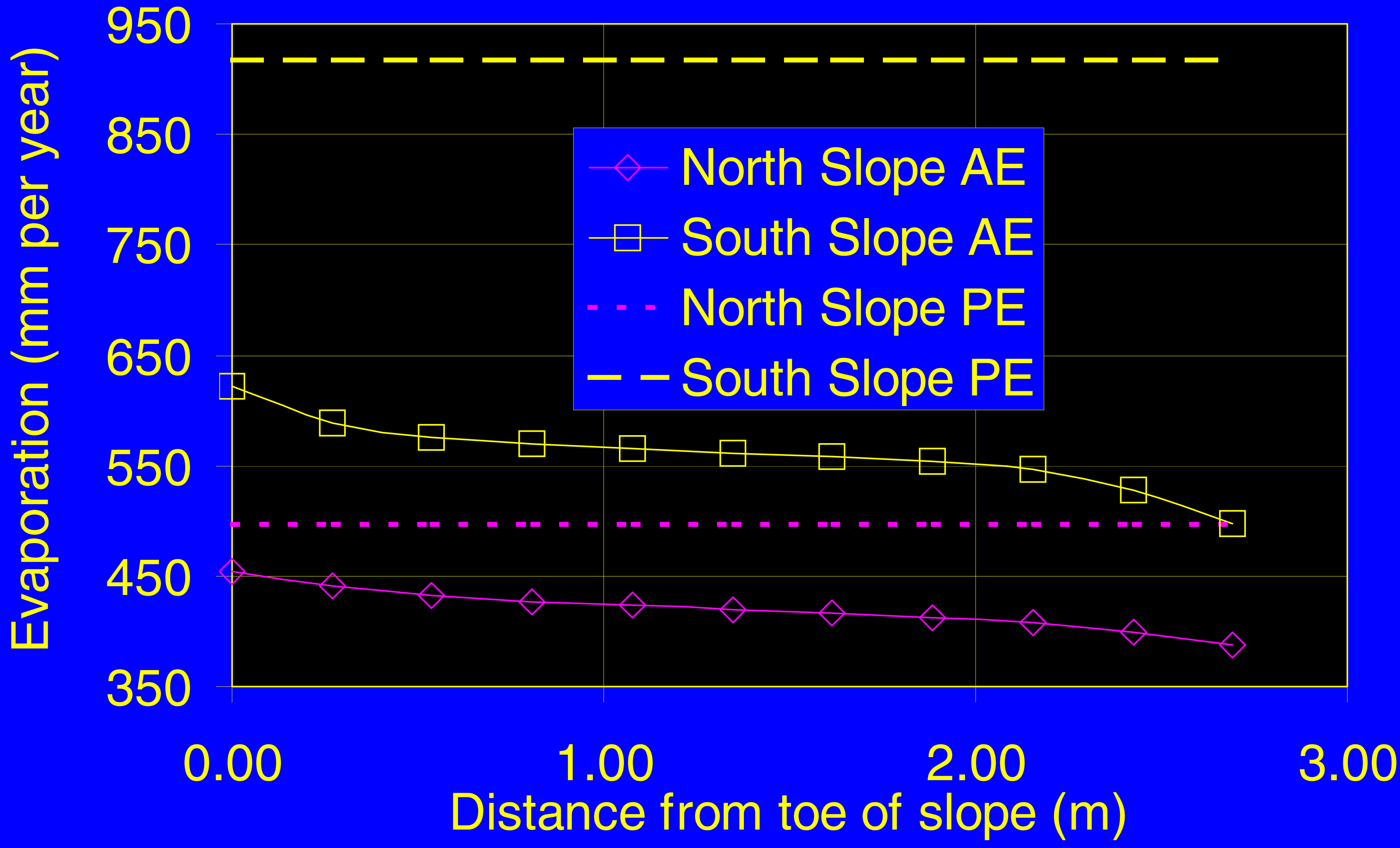
Impact of Slope on Evaporation



Application with 2D analysis



Impact of moisture distribution



Conclusions

- Slope angle and orientation can significantly affect evaporation
- Variations in net radiation with slope drive variations in the evaporation rate
- These variations in net radiation are predictable, and a model has been developed to make this predictions

More Conclusions

- The radiation model can be incorporated with existing models for flux boundaries, to improve evaporation estimates.
- Some potential design applications:
  - Optimizing material placement (variable thickness on cover layers)
  - Locating dump sites to maximize evaporation
  - Variable evaporation from tailings dams

End