Development of a Soil Depth Estimates for use in CLM

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General motivation of accounting for variations in soil depth

Global

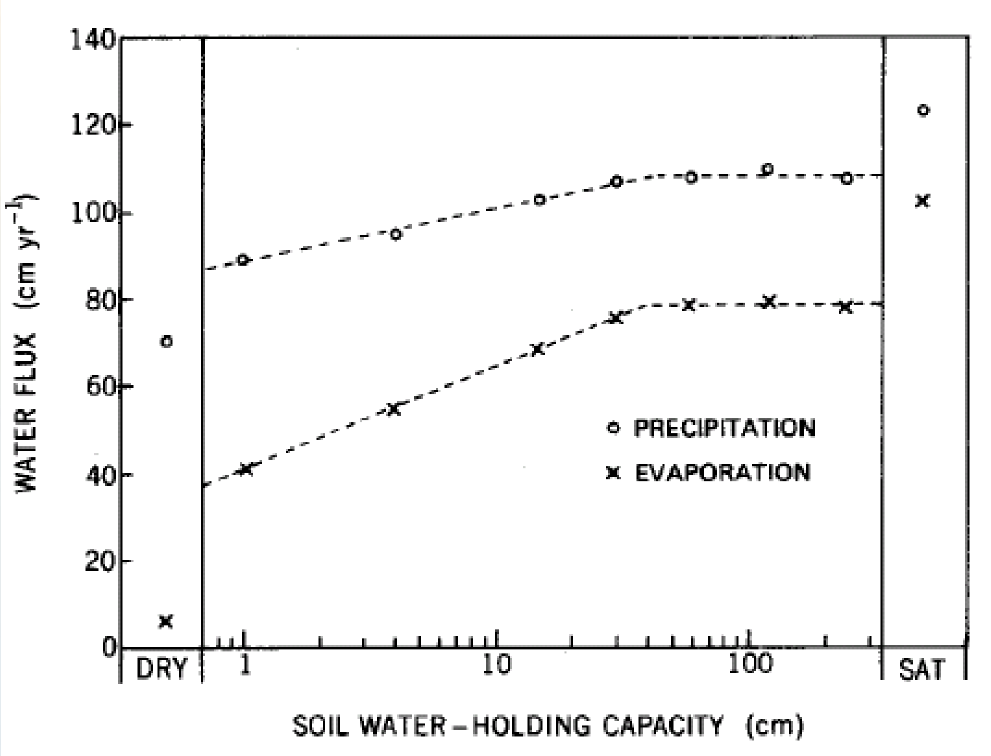

FIG. 12. Annual evaporation and precipitation (cm yr^{-1}), averaged over all land areas, for each simulation.

- Global Hydrology: (Milly 1994, Milly and Dunne, 1994)
- Rodriguez-Iturbe and Porporato, 2004
- Bertoldi et al., 2006

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Why variability in soil depth/soil water holding capacity may be important

- Complex terrain and therefore large regions steep slope and thin soils

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Why variability in soil depth/soil water holding capacity may be important

- Large regions of ‘poorly developed’ soils (AZ-NM, NW Mexico)
- Water limited ecosystems (as opposed to energy or other)

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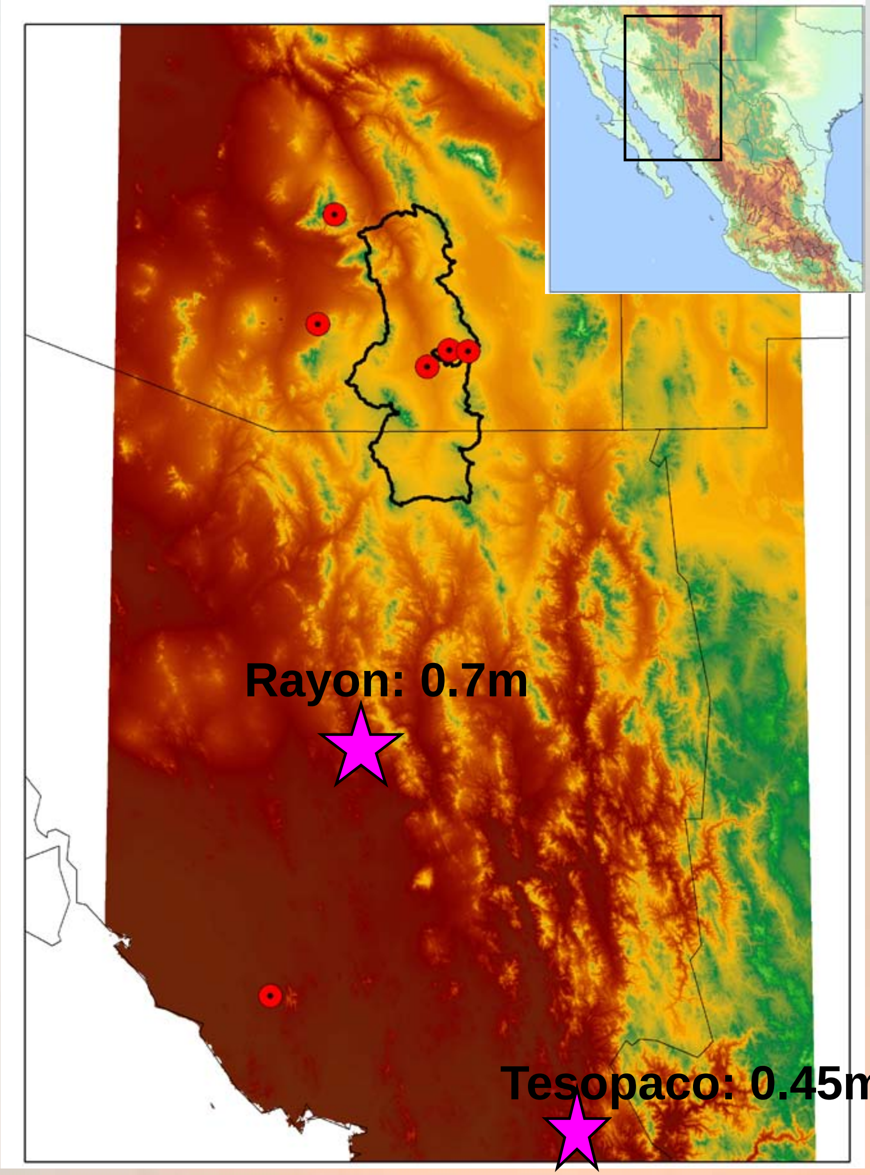
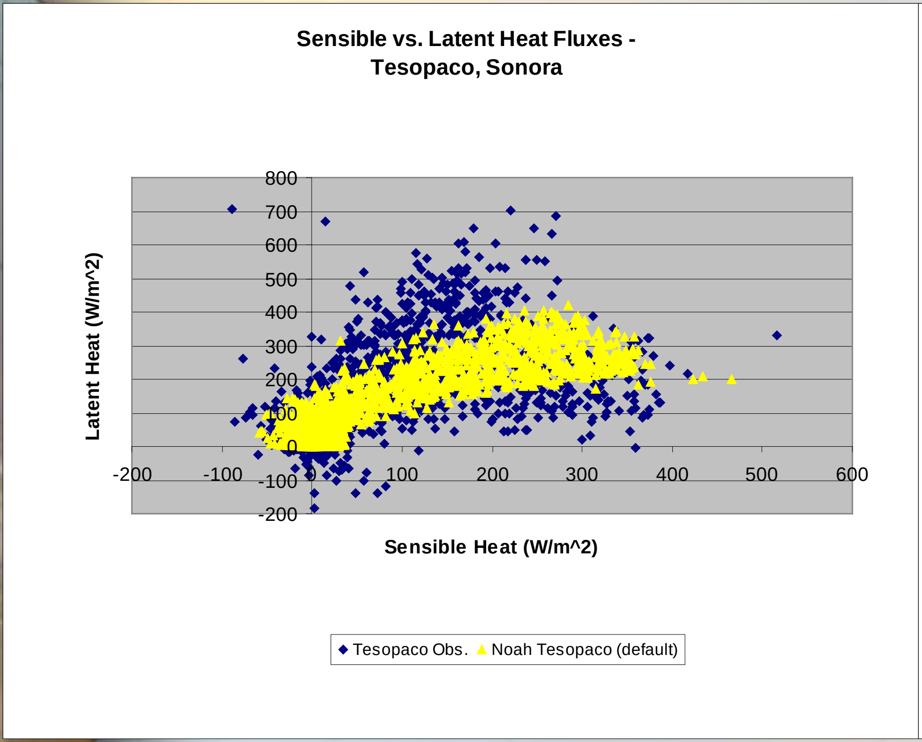
NAM Tower Flux Sites:

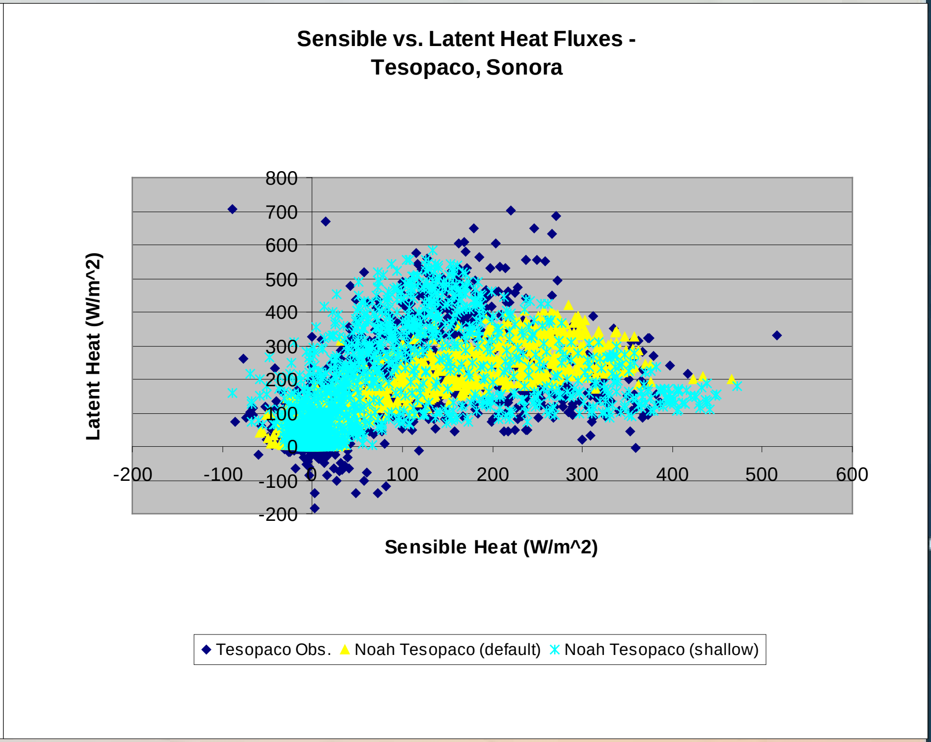
- Rayon/R. Sonora, Son. (23 Jul. – 30 Sep. 2004): Complex terrain, deciduous scrub, shallow impervious layer at 0.7m (Vivoni et al, 2007, J.Climate)

- Tesopaco, Son. (2004): Tropical Deciduous Forest, impervious layer at 0.45 m (Watts et al., 2007, J. Climate)



Partitioning of sensible and latent heat fluxes: Tesopaco, Sonora - 2004





- Default implementation of Noah LSM shows a positive bias in H over LE compared with obs
- Moreover Noah model is ‘underdispersive’ with respect to its range in LE and H flux values
- Reduction in soil depth from 2m to 0.45m results in clear broadening of flux values, particularly high LE, but no improvement in bias

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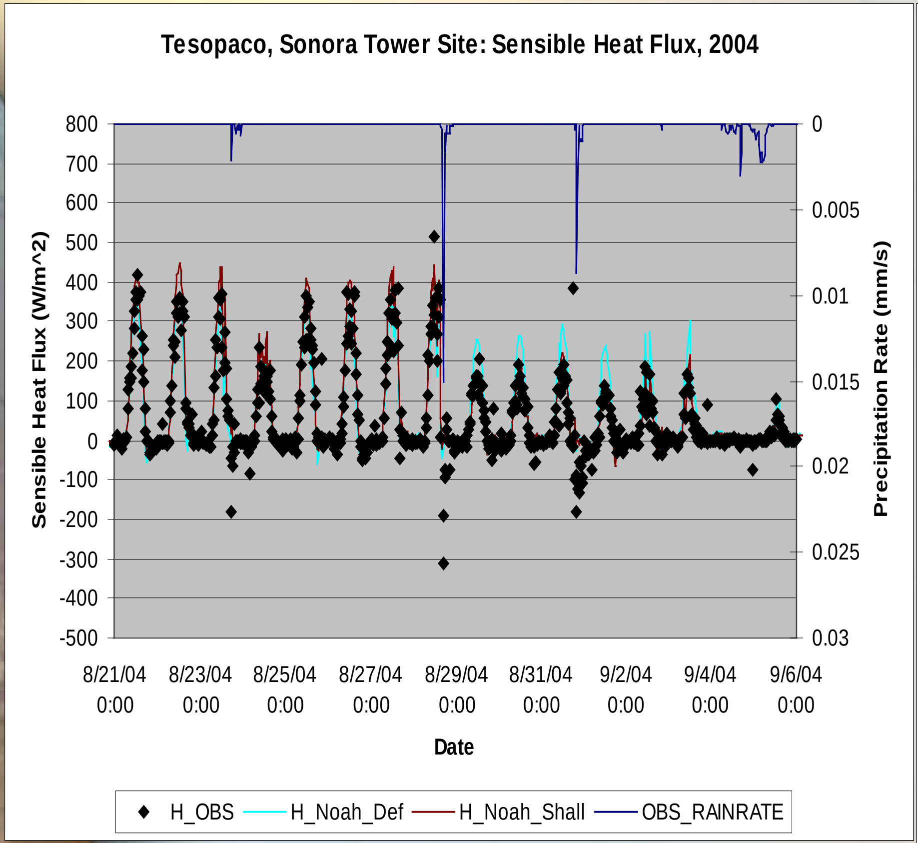
Verification of sensible and latent heat fluxes: Rayon and Tesopaco, Sonora - 2004

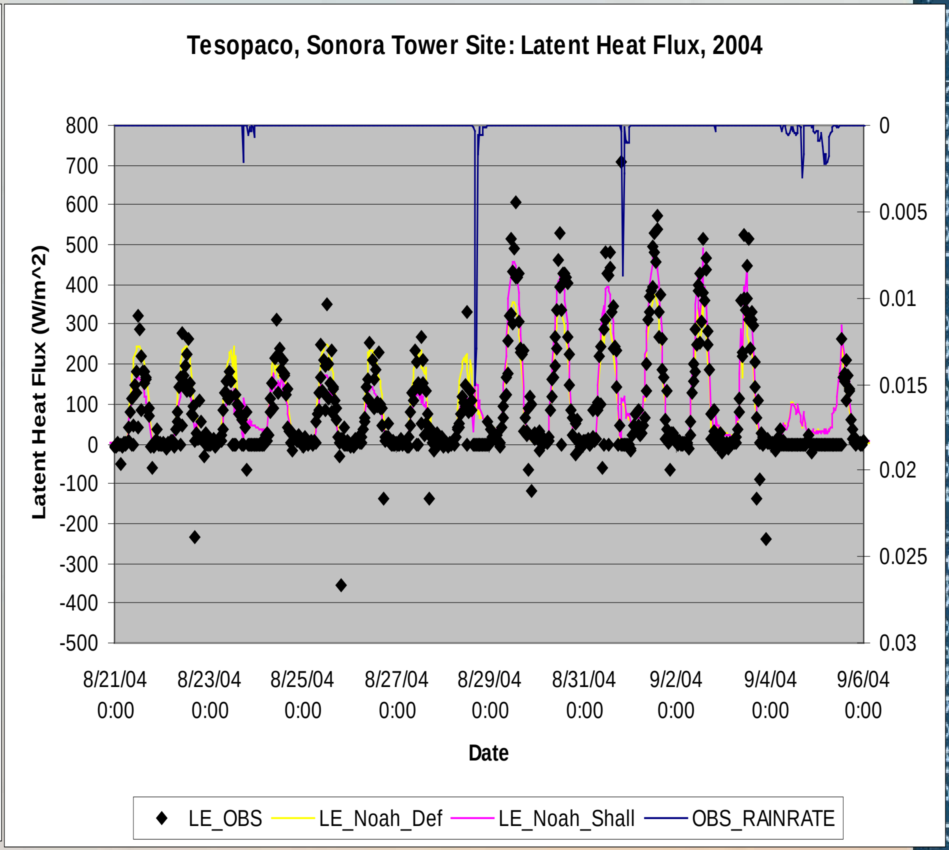
	H Tesopaco	LE Tesopaco
Correlations:	0.89 / 0.90	0.89 / 0.91
Nash-Sutcliff Eff.:	0.69 / 0.80	0.79 / 0.80
RMSE:	54 / 44	68 / 65

(deep soil / shallow soil)

- Equivalent or improved model performance of shallow vs. deep soil specification as indicated by a selection of quantitative metrics

Tesopaco, Son. Tower Site: Aug. 22- Sep. 2, 2004





- Differences of approx. 50 – 120 W/m^2 in peak flux values
- General underestimate of peak H and overestimate of peak LE during dry periods in default simulation
- Alternatively, response to precip. events modestly improved in terms of peak H reduction and peak LE amplification

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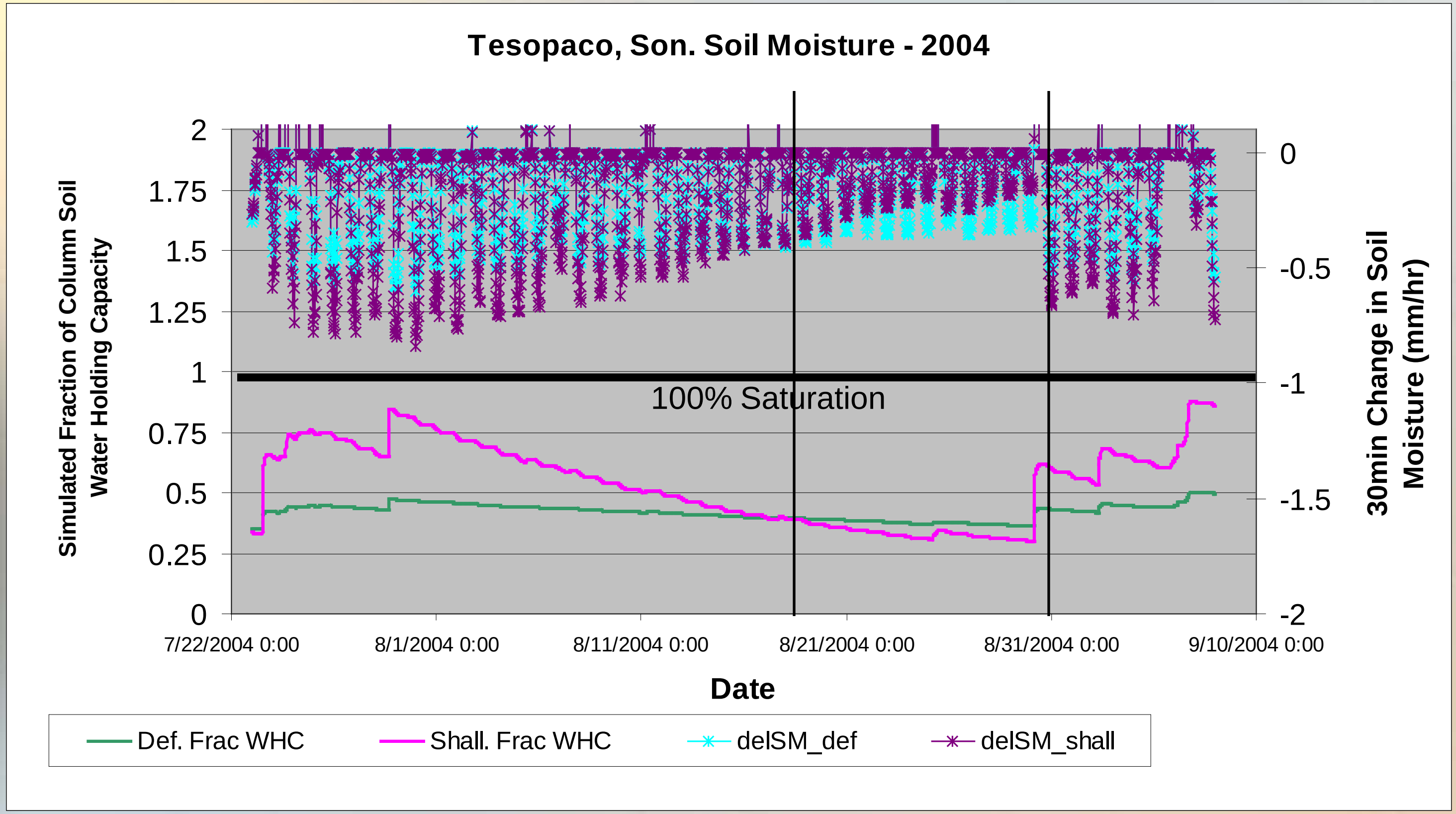
Tesopaco, Son. Tower Site: 2004



- At the wetter Tesopaco site, impacts are more pronounced in response to heavier rainfall inputs
- Greater ET in shallow soil case for few days following recharge event
- Long dry-down period in late Aug. still exhibits rapid depletion of soil water
- Cross-over points in water content directly relate to relative dominance of time-step ET between shallow and deep soil models

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Conclusions thus far…

- Inclusion of variable soil depths can have an appreciable impact on surface sensible and latent heat fluxes
- Impact largely appears manifested through changes in soil water holding capacity resulting in larger variations in fractional soil water content in shallow soils (*increased dynamic range*)
- Essentially, fractional soil water content increases more rapidly during recharge events and decreases more rapidly during drydowns
- Through model ET-soil moisture stress function, larger changes in fractional soil water content impart large influence on ET

- Unresolved issues:
  - Impact of bottom boundary conditions:
    - Impermeable vs fractured bedrock
    - ‘Deep’ soil temperature specification (VIP for snow pack/melt, frozen soils)
    - Groundwater
  - *Need spatially distributed estimates of soil depth*
  - Influence in coupled land-atmo simulations (PBL growth, convx. init.)
  - Impact of horizontal routing processes in saturated soils in complex terrain

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Inclusion of variable soil depths in LSM's

- Imperatives for LSM/coupled land-atmosphere applications
  - Distributable, 'generalizable'
  - Verifiable (at least potentially or partially)
  - Scalable (or scale-invariant?)

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Estimating soil depth from DEMs (D-B)

$$\rho_s \frac{\partial h}{\partial t} = -\rho_r P_o e^{-mh} - k\rho_s \nabla^2 z$$

Change in soil depth with time

Soil production function = f(soil depth)

Soil loss (diffusion-transport) function

Dietrich et al., 1995, Hyd. Proc.
Heimsath et al., 1997, Science

$$h = -\frac{1}{m}\ln\left(-\frac{k\nabla^2 z}{P_o \cdot \rho_r / \rho_s}\right) = \frac{1}{m}\ln\left(\frac{\nabla^2 z_{crit}}{\nabla^2{}_z}\right)$$

Bertoldi et al., 2006, J. Hydromet.

- **Diffusional, steady-state, curvature-based erosion model**
- **For Noah constrain soil depths from 0 - 200cm**

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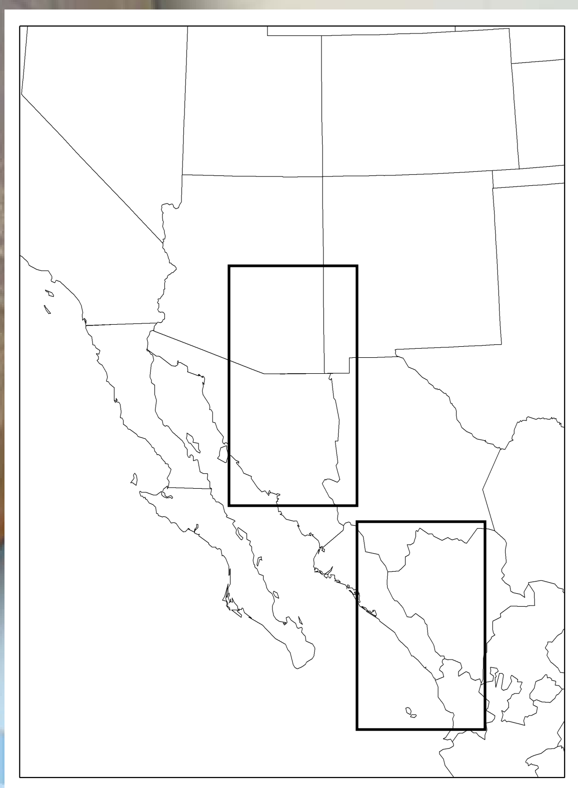
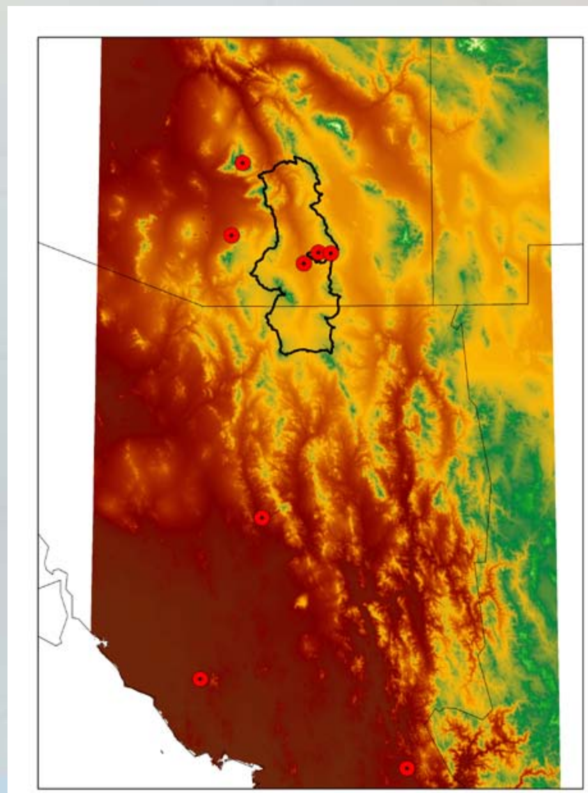
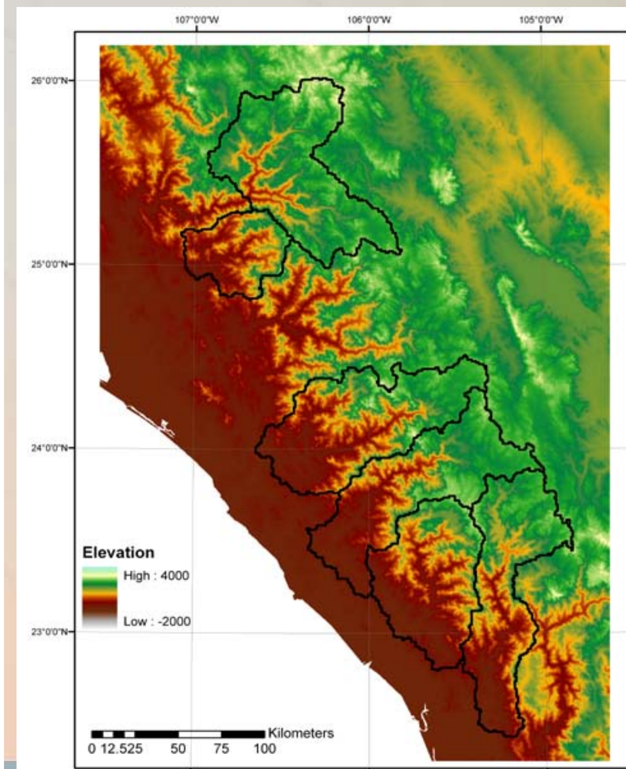
Estimating Soil Depth in the NAM Region

- Verification against tower flux sites (estimates of soil depth as well as simulated fluxes using those values)
- Basin average values of soil depth







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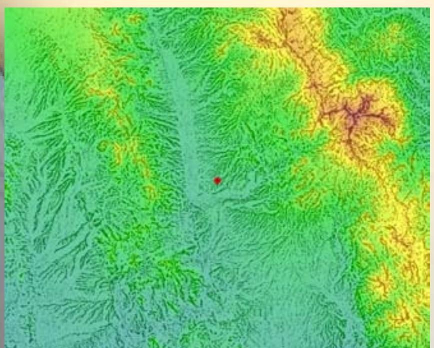
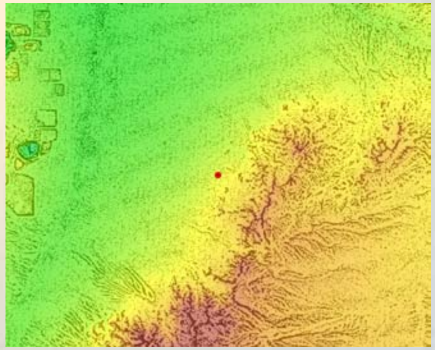
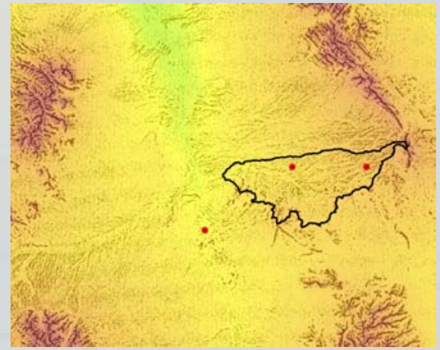
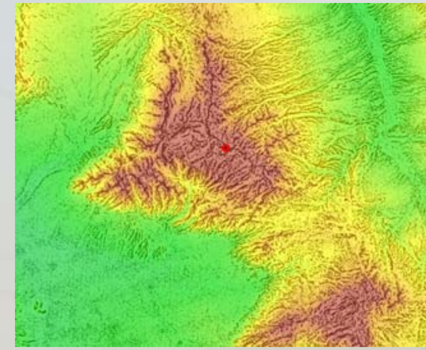
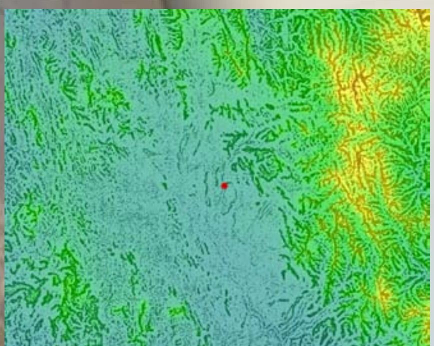
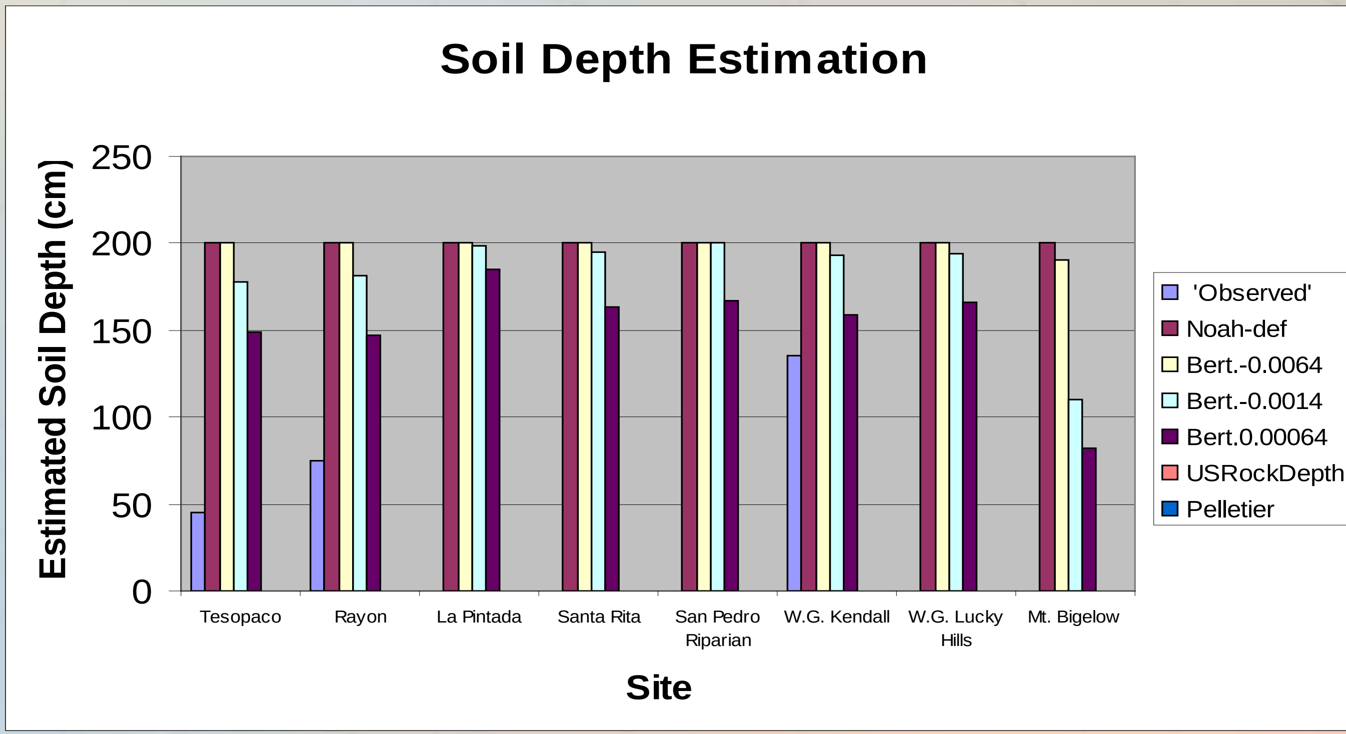
Tower site estimation: D-B



- 90m ‘Hydrosheds’ DEM
- 5x5 average of nearest pixels

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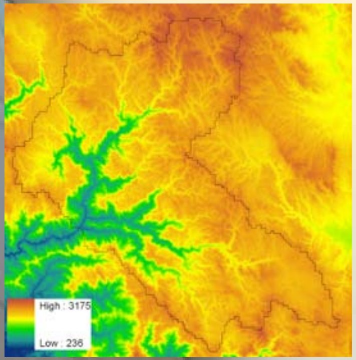
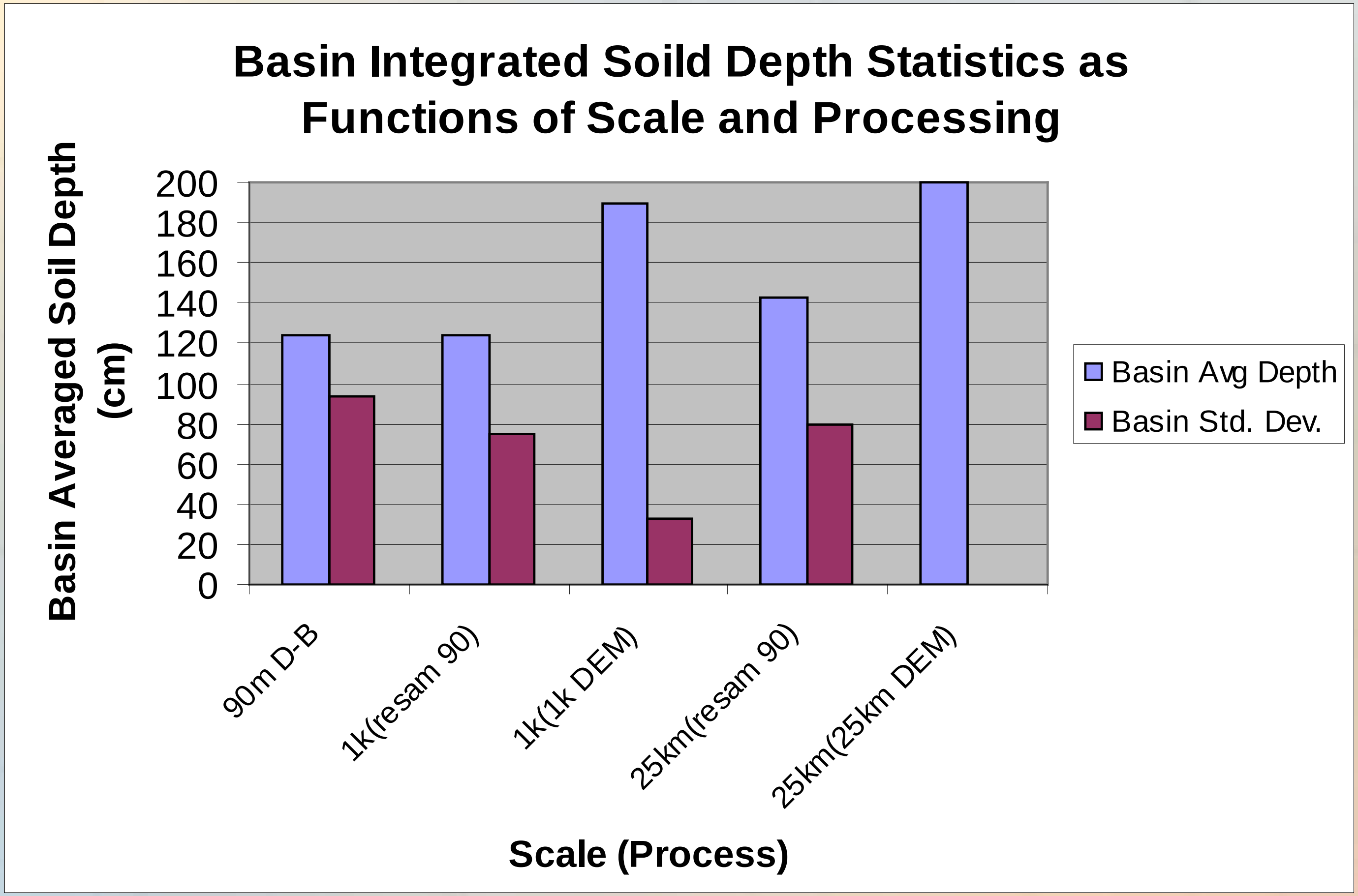
Estimating Soil Depth : Scale Considerations



Rio Humaya



- Derivation of soil depth from coarse DEMs does not preserve statistical structure (mean and stdev)
- Reasonable coarse resolution soil depth estimates can be derived by resampling fine-resolution estimates

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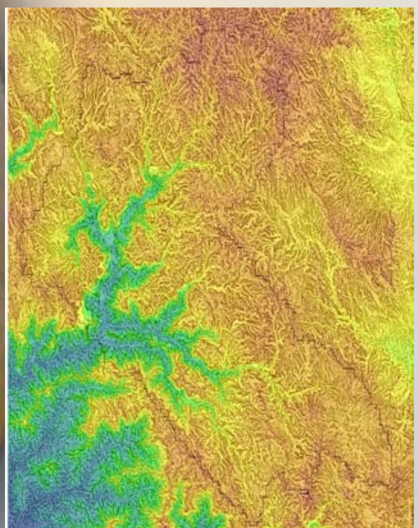
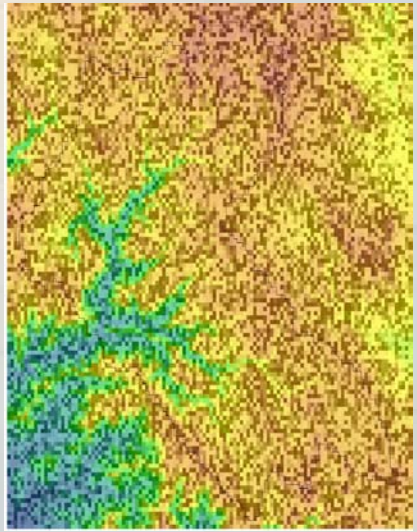
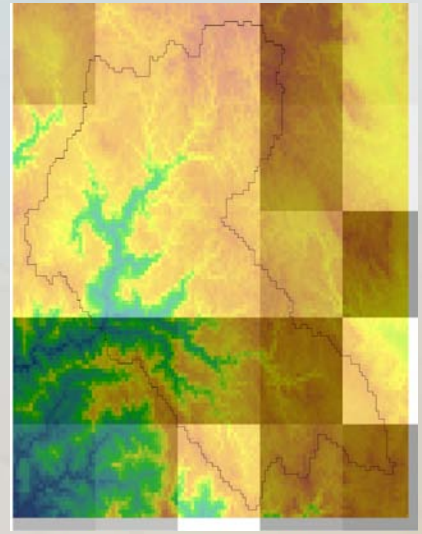
Estimating Soil Depth : Scale Considerations



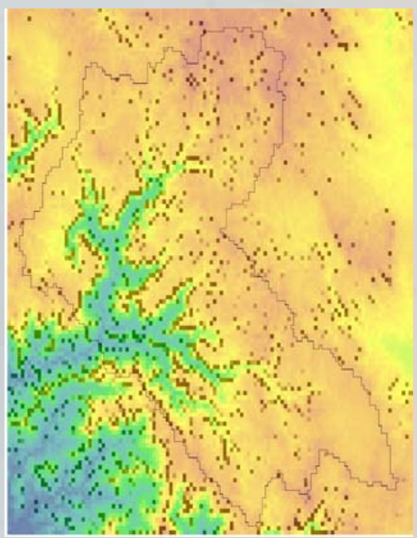
90m Soil Depth



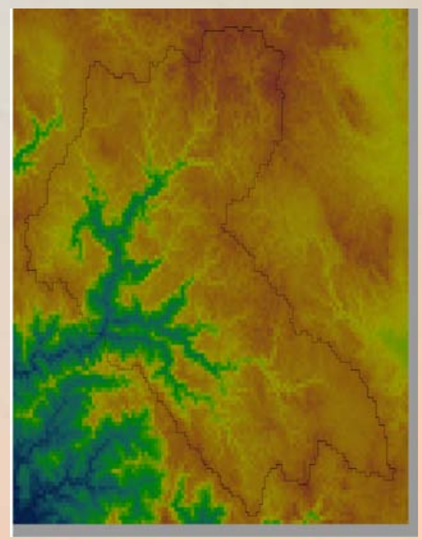
1km – resampled



25km – resampled

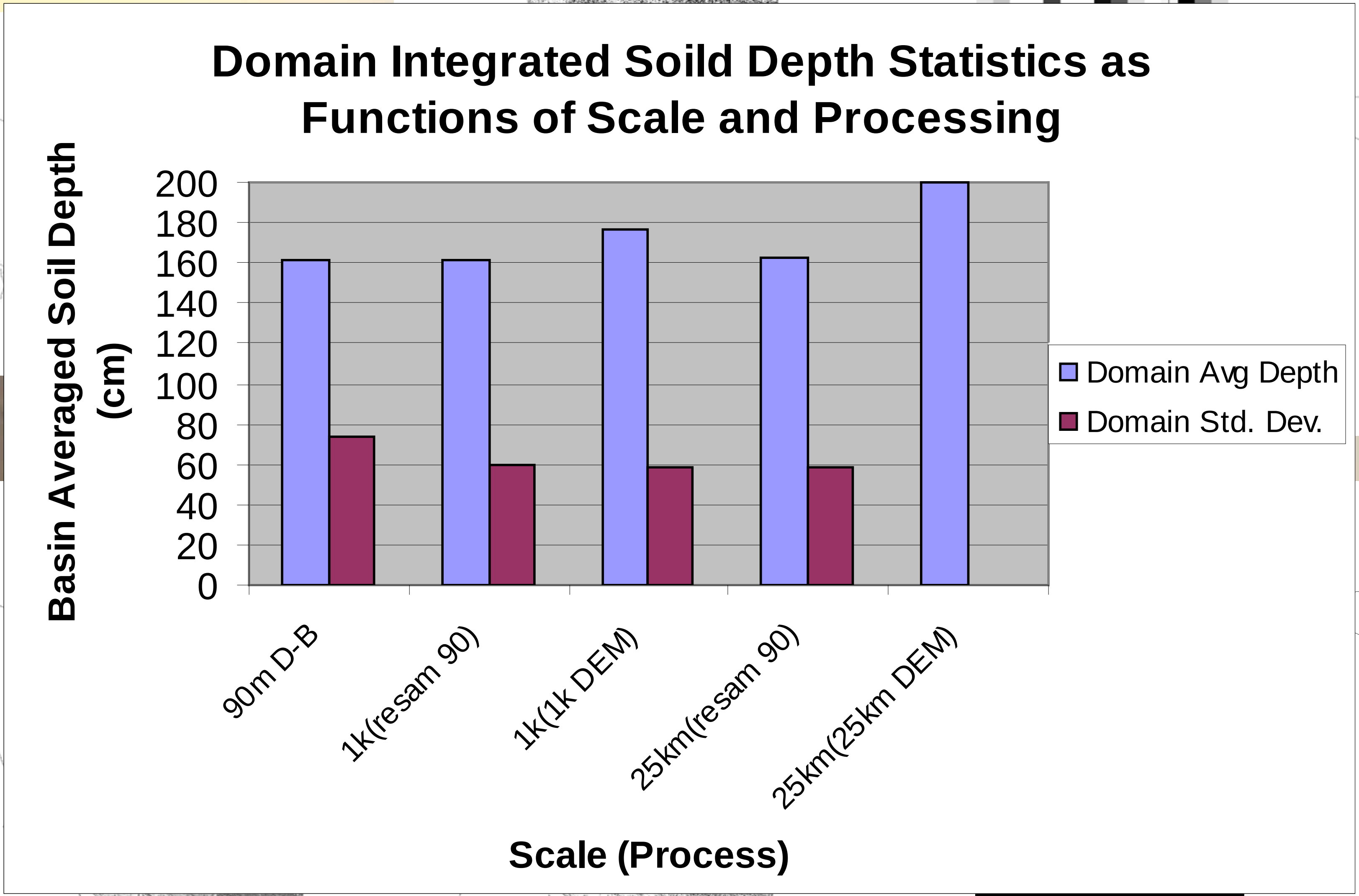


1km DEM



25km DEM

Estimating Soil Depth : Scale Considerations



90m Soil Depth

1km DEM

25km DEM

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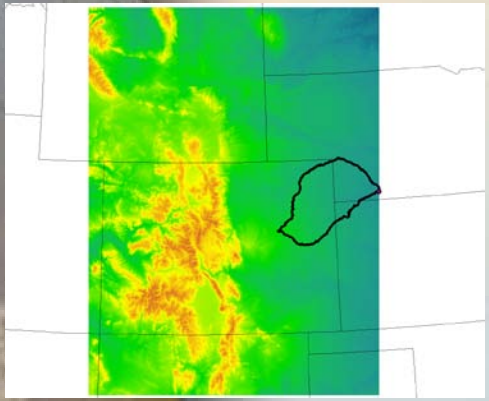
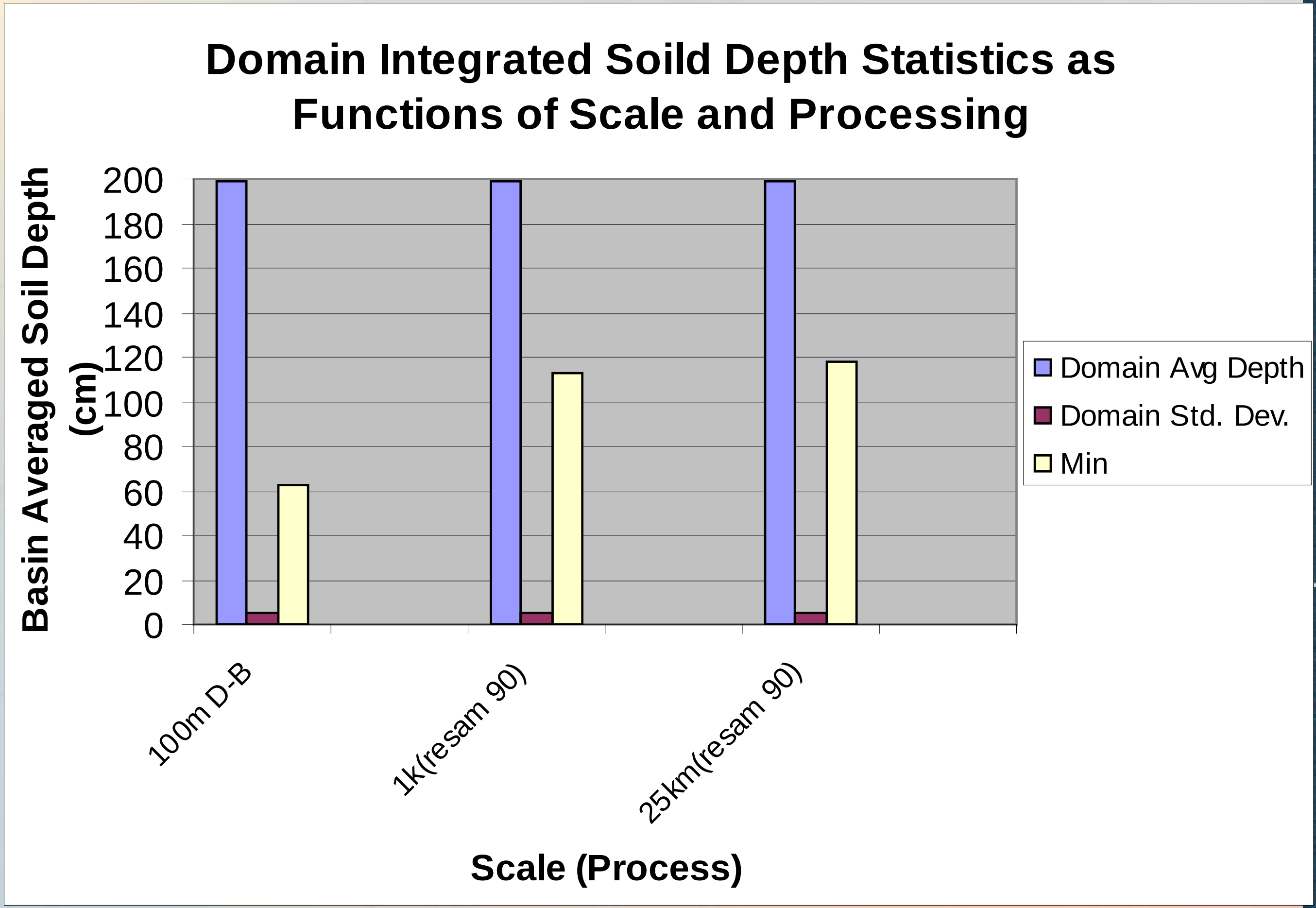
Estimating Soil Depth : Out on the plains…





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Conclusions and Future Work:

- Conclusions:
  - Variations in water holding capacity impact surface fluxes through increasing the dynamic range of water content/matric potential and the ET-soil moisture stress relationship
  - Spatially-distributed estimates of soil depth from DEMs appear possible using geomorphic theory (not local empirical relationships)
  - Products derived at high resolution can be aggregated while generally preserving ‘basin’ mean values (not variances), loss of spatial covariance
- Future Work: Explore these impacts in coupled model simulations in CLM4

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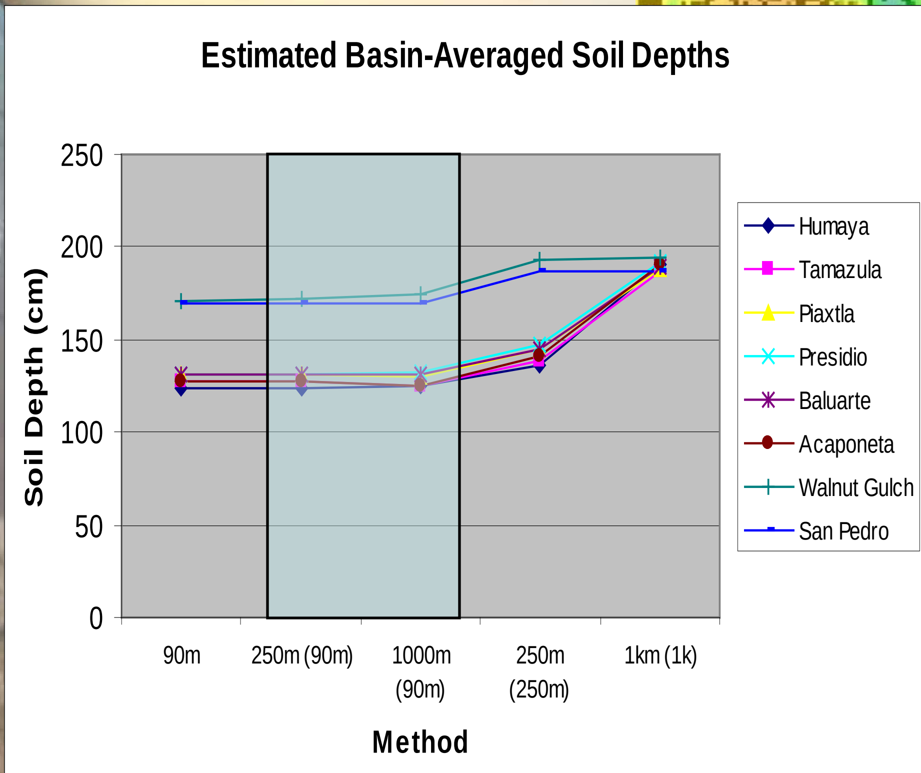
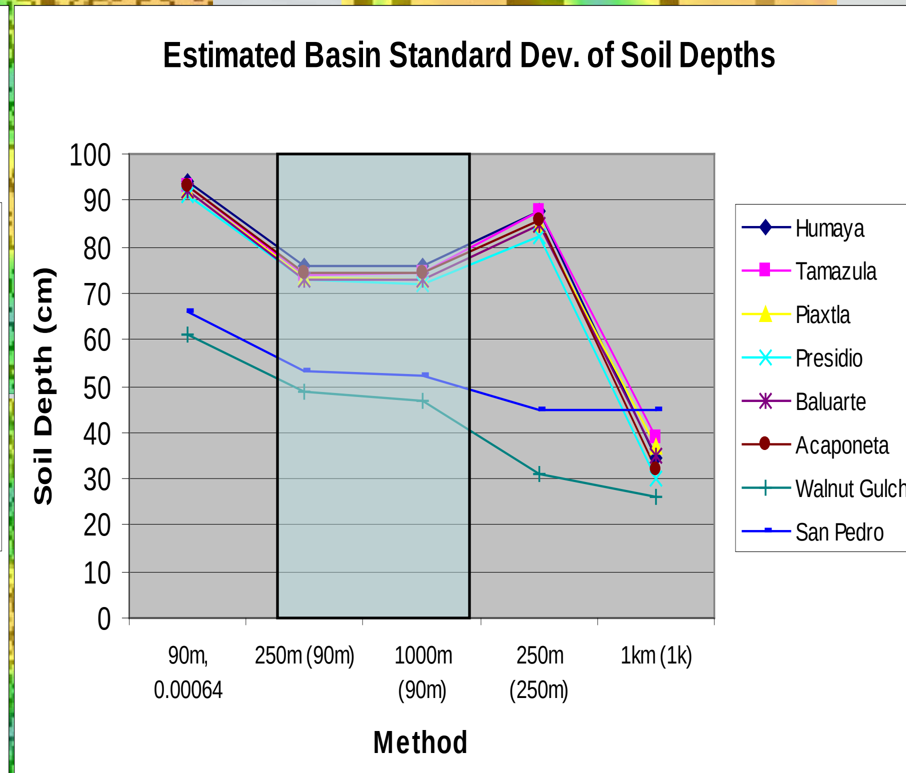
Estimated Soil Depth in the NAM region (D-B method): River basin statistics and scaling properties





- Directly re-sampled soil depths (90 to 250 or 1000) generally preserve basin mean value although variances (std dev.) drops
- Clear increases in mean value of soil depth when derived from re-sampled (coarser) DEMs
- Peculiar behavior in 250m std deviation when derived from re-sampled DEM???
- All basins contain points minima with 0 soil depth
- Inter basin differences are modest (constrained estimates?)

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