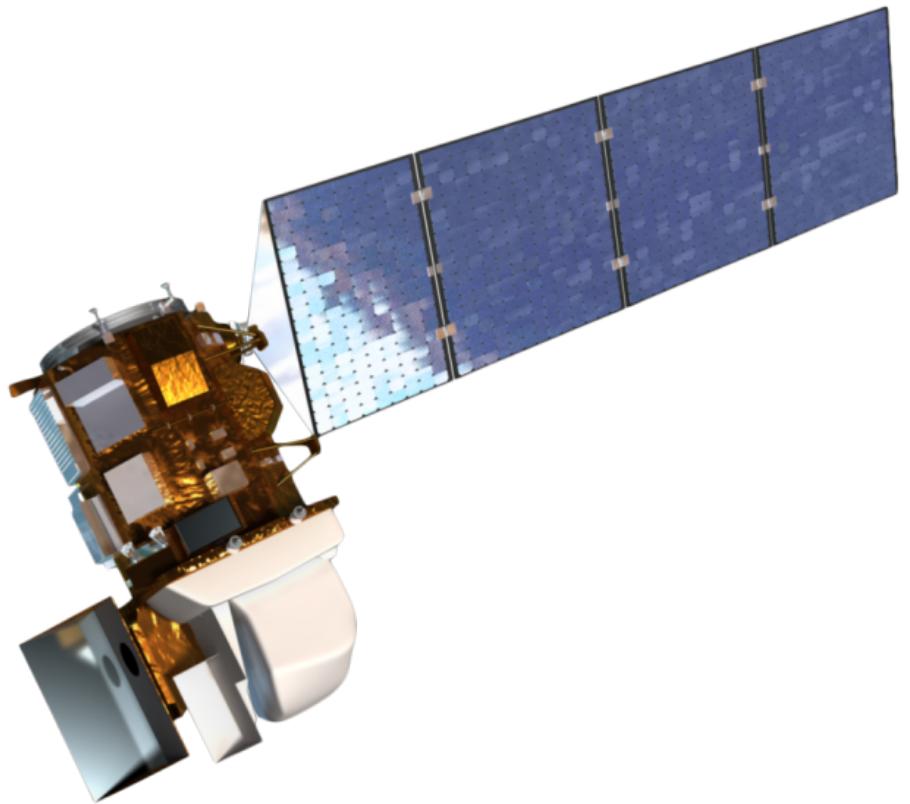


Sliding-window techniques

Anne Denton's Research Group

Traditional Technology: Landsat

- Since 1972
- 30 m resolution
 - Few hundred pixels per field
- Large satellites
- ~ 700 km altitude
- Weighs 5.8k pounds
- Landsat 8 newest



What to use it for?

Agriculture perspective

- Getting information from agricultural fields without going there
 - Recognizing crop disease / storm damage
 - Knowing what is planted where (crop cover)
- Predicting crop quantity / quality
 - Yield prediction (typical machine learning challenge)
 - Knowing where to apply fertilizer
 - Recognizing other chemical deficiencies
 - Understanding water stress
- Understanding soil problems
 - Salinity
 - Erosion

Machine learning perspective

- Mostly classification or regression problems
- Typically lack of training data
- Typically risk of losing access to training data
- Solutions:
 - Predicting land use
 - Use of independent information as proxy

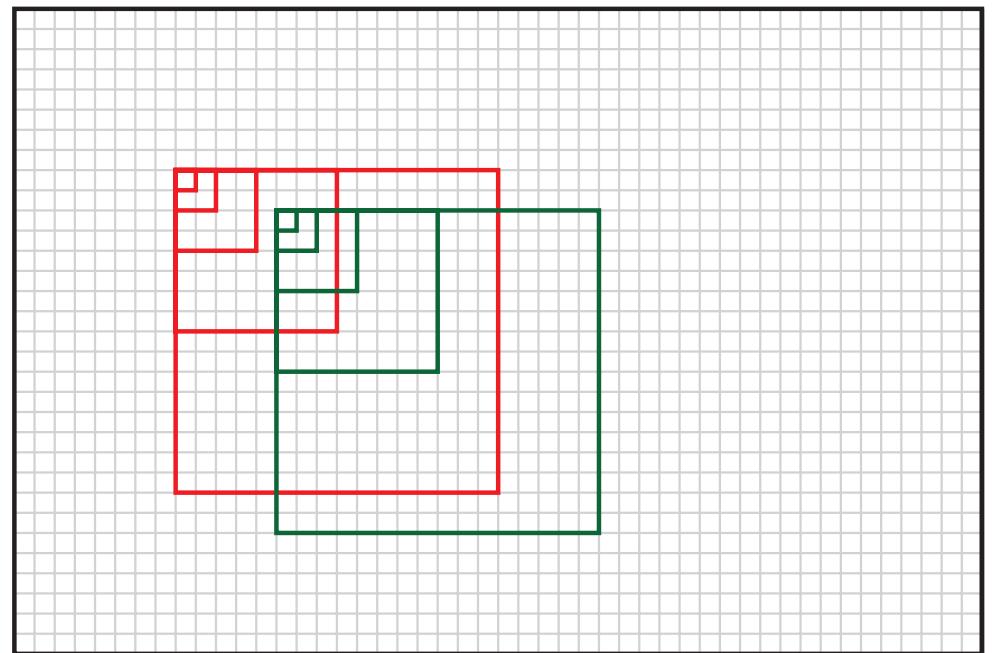
New Technology

- Cube sats
 - 3m resolution
 - 450 km altitude
 - Weigh 9 lbs
 - 88 satellites
- Drones
 - 1-10 cm resolution



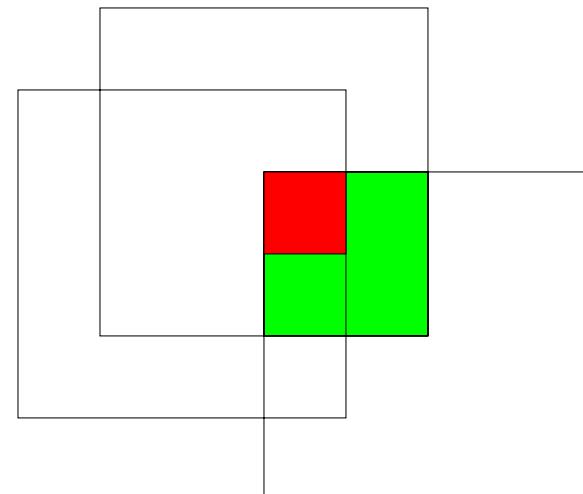
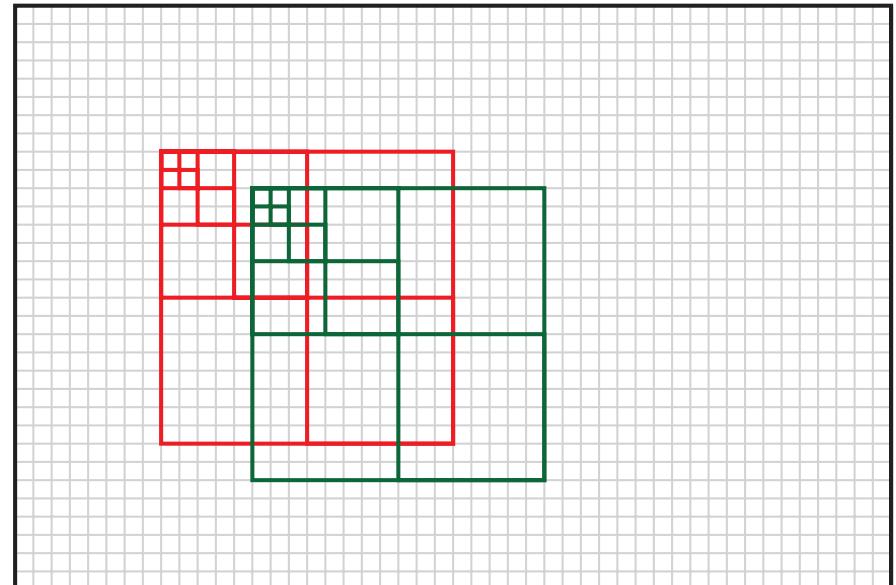
What do you do with that resolution?

- Question: Why do I care about cm resolution if farm implements are 100 feet wide?
- Instead of 1 pixel you get up to 100
- You don't even have to lose resolution



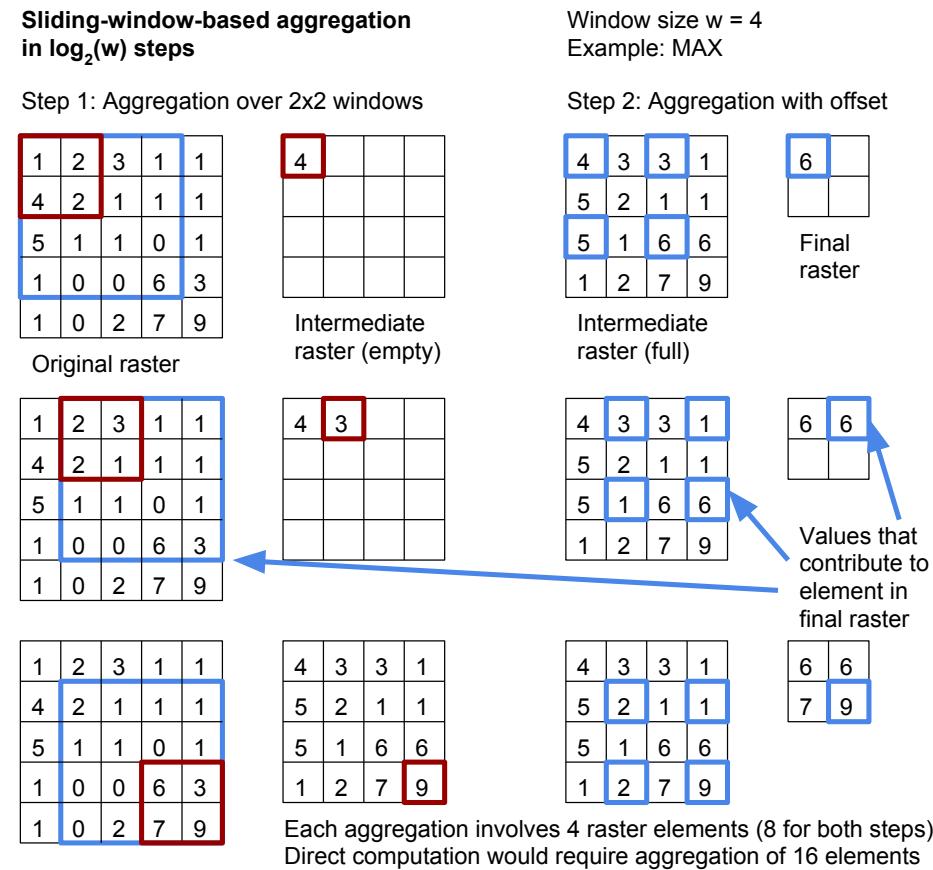
Is it too computationally expensive?

- Efficient algorithm for linear aggregates
 - SUM / COUNT
 - MAX / MIN
 - Sums of squares
 - Sums of higher order terms
- Problems for
 - MEDIAN



Algorithm

- For window size w , image size is $\text{size}-w+1$
- Windows that are aggregated are $\delta = w/2$ apart
- Most aggregates get reused 4 times

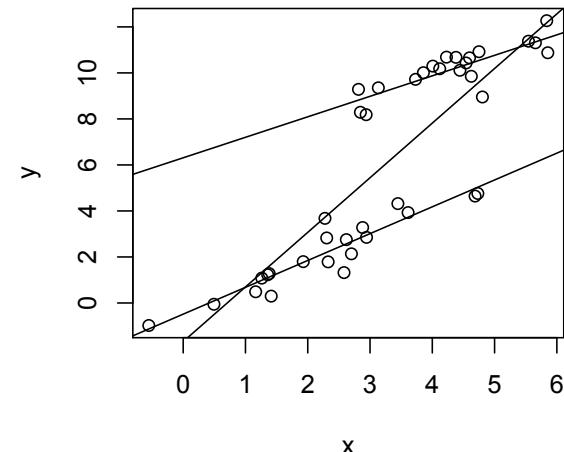
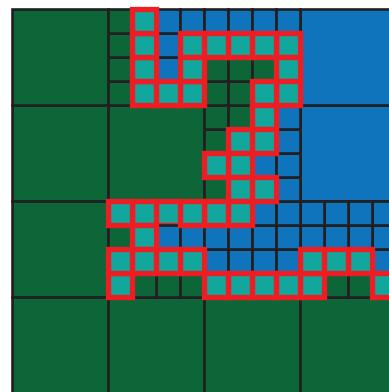
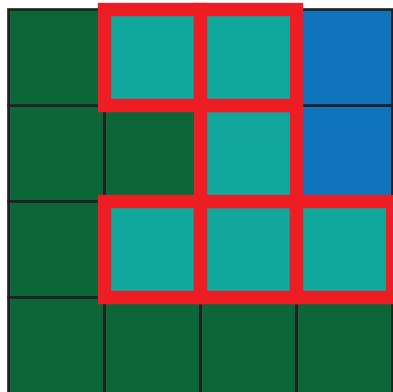


Limitation to “linear” aggregates

- Linear models, but not necessarily linear regression
 - Much of statistics uses linearity
 - Linear models dominate regression
- What does “linear” mean?
 - A fit with a quadratic polynomial is still a linear model
 - It is linear in the parameters
- If you wanted to use polynomial regression across multiple databases, you could locally compute
 - Count, sums, sums of squares, sums of higher order terms
 - Aggregate the aggregates in a central place
- Same holds for iterative aggregation of windows

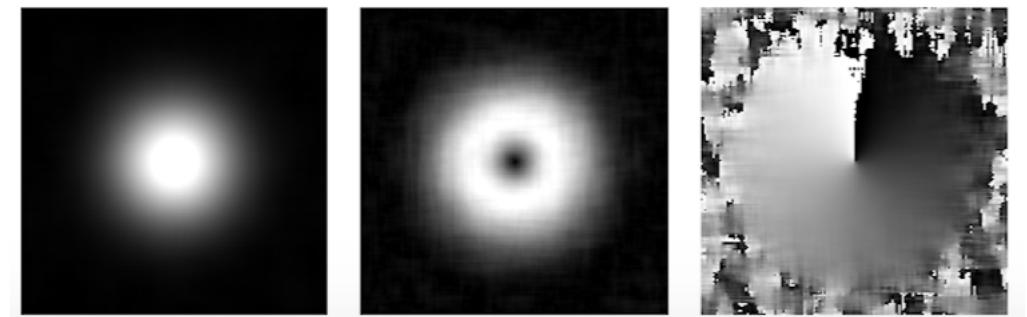
Some Approaches so far

1) Regression



2) Fractal Dimension

3) Topography



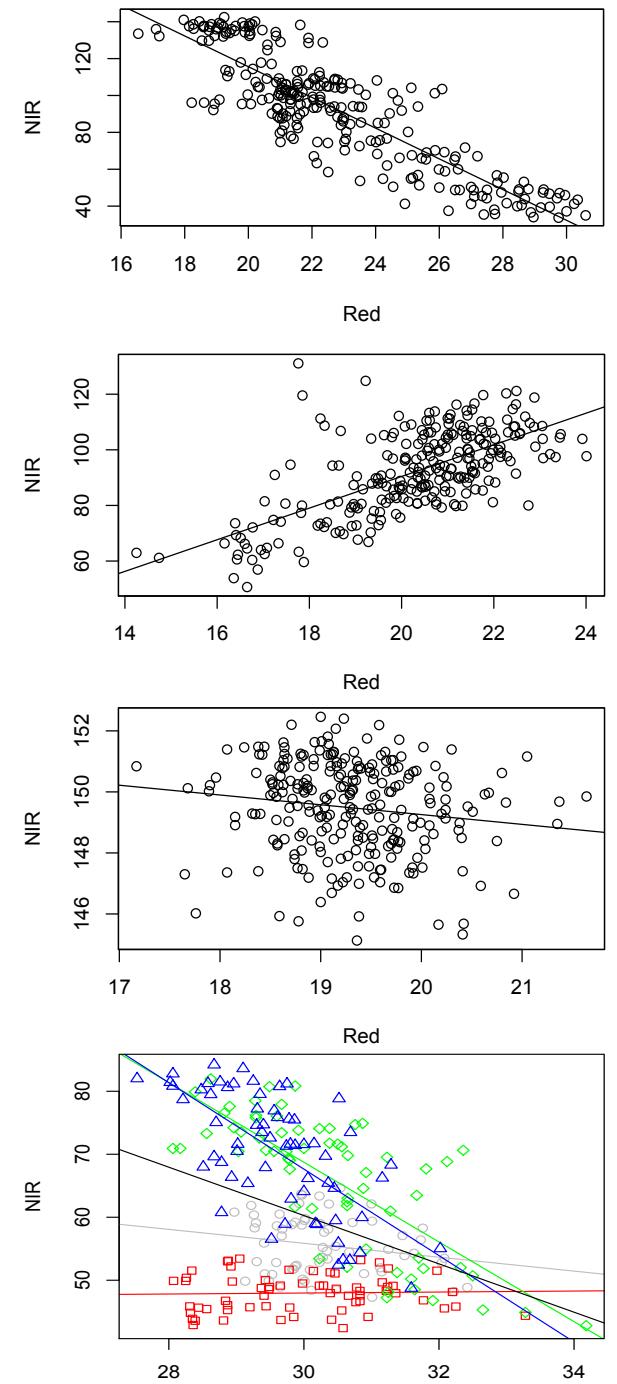
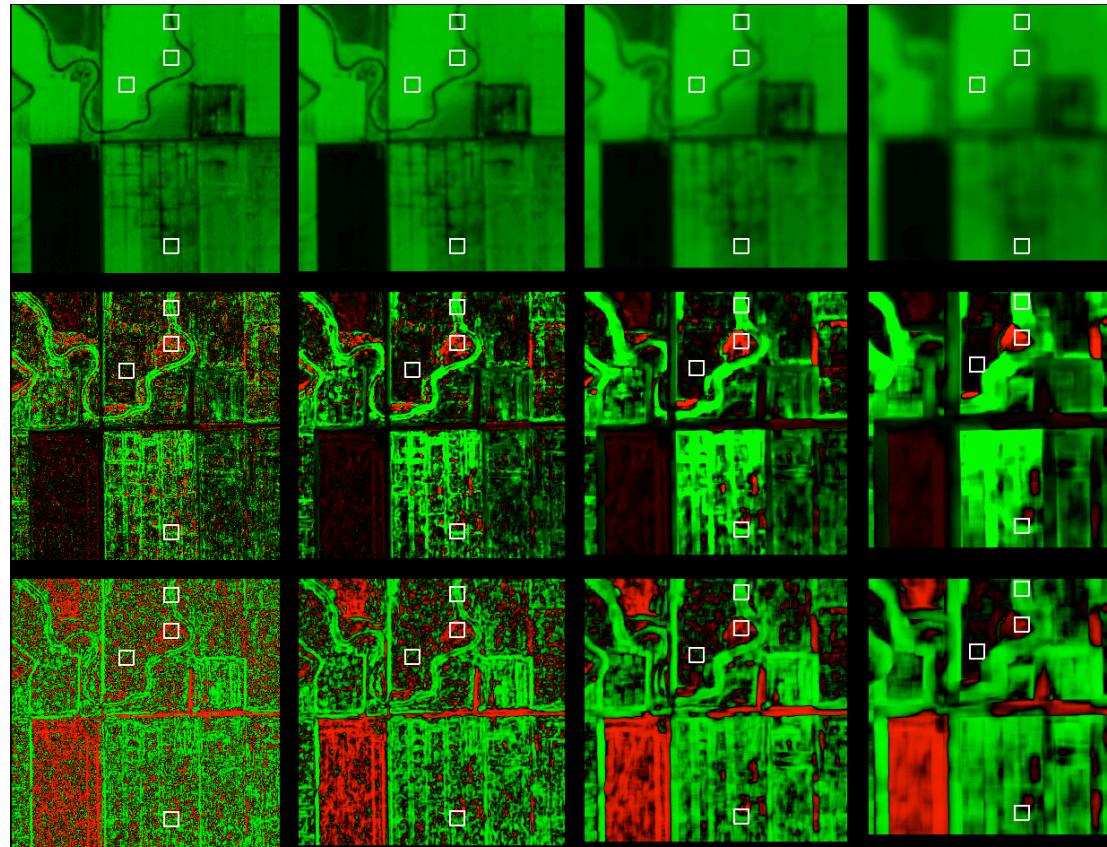
Regression

- Linear regression
- Aggregation done for all 5 aggregates
- (Pearson correlation also uses y^2)
- We could use higher order polynomials but haven't
(Polynomial regression is still a linear model)

$$slope = \frac{N \sum x_{ij}y_{ij} - \sum x_{ij} \sum y_{ij}}{N \sum x_{ij}^2 - (\sum x_{ij})^2}$$

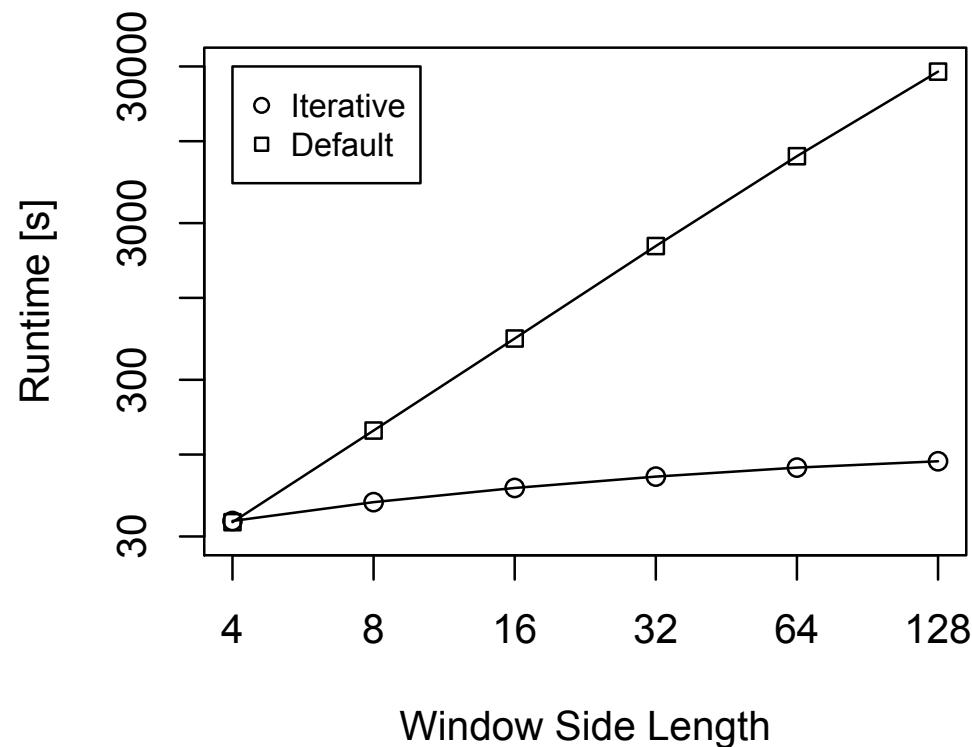
$$z_{ij}^{(base)} = \text{any of } \begin{cases} x_{ij} \\ y_{ij} \\ x_{ij}^2 \\ y_{ij}^2 \\ x_{ij}y_{ij} \end{cases}$$

Results of NIR vs. Red Band



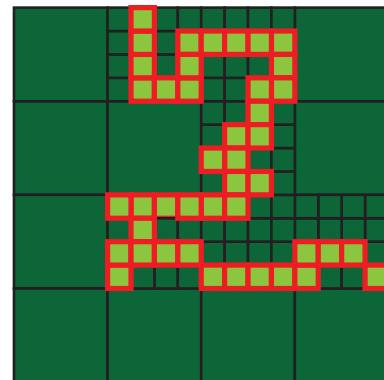
Performance

- Scaling logarithmic in window size
- Dramatic difference for large window sizes

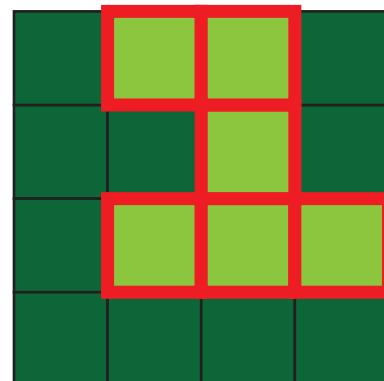


Fractal Dimension

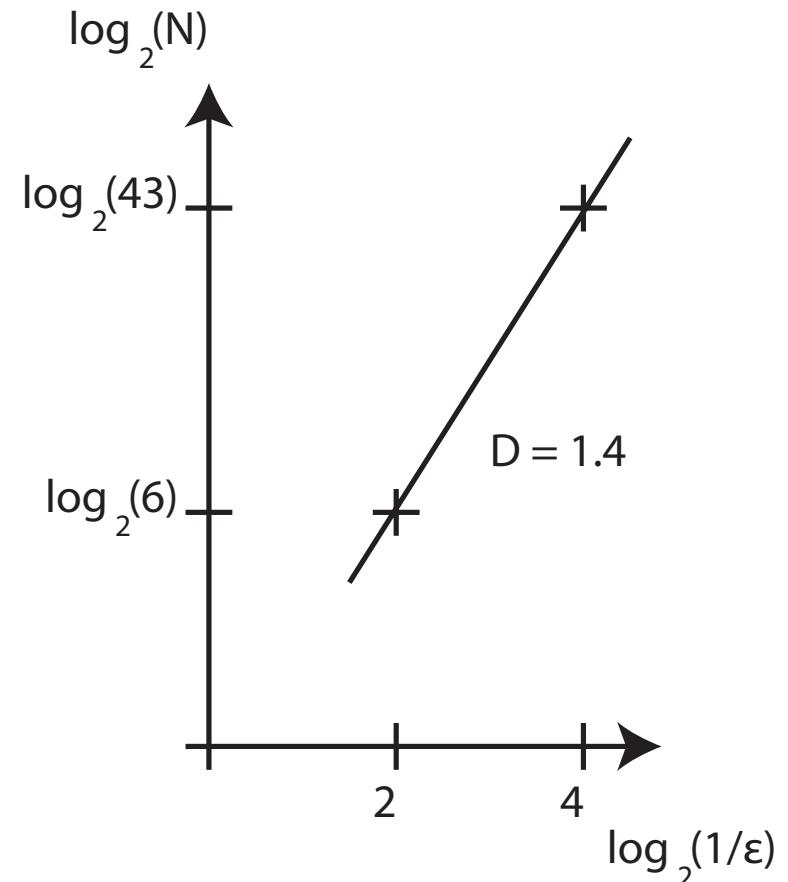
- Motivation
 - Length of shoreline of England
- Fractals proposed by Benoit Mandelbrot
- Captures self-similarity
- Used extensively for past 50 years
 - Used in image processing
 - Including urban growth
- **Only uses sum and max**
- https://en.wikipedia.org/wiki/Koch_snowflake



$$\begin{aligned}N &= 43 \\ \varepsilon &= 1/16\end{aligned}$$

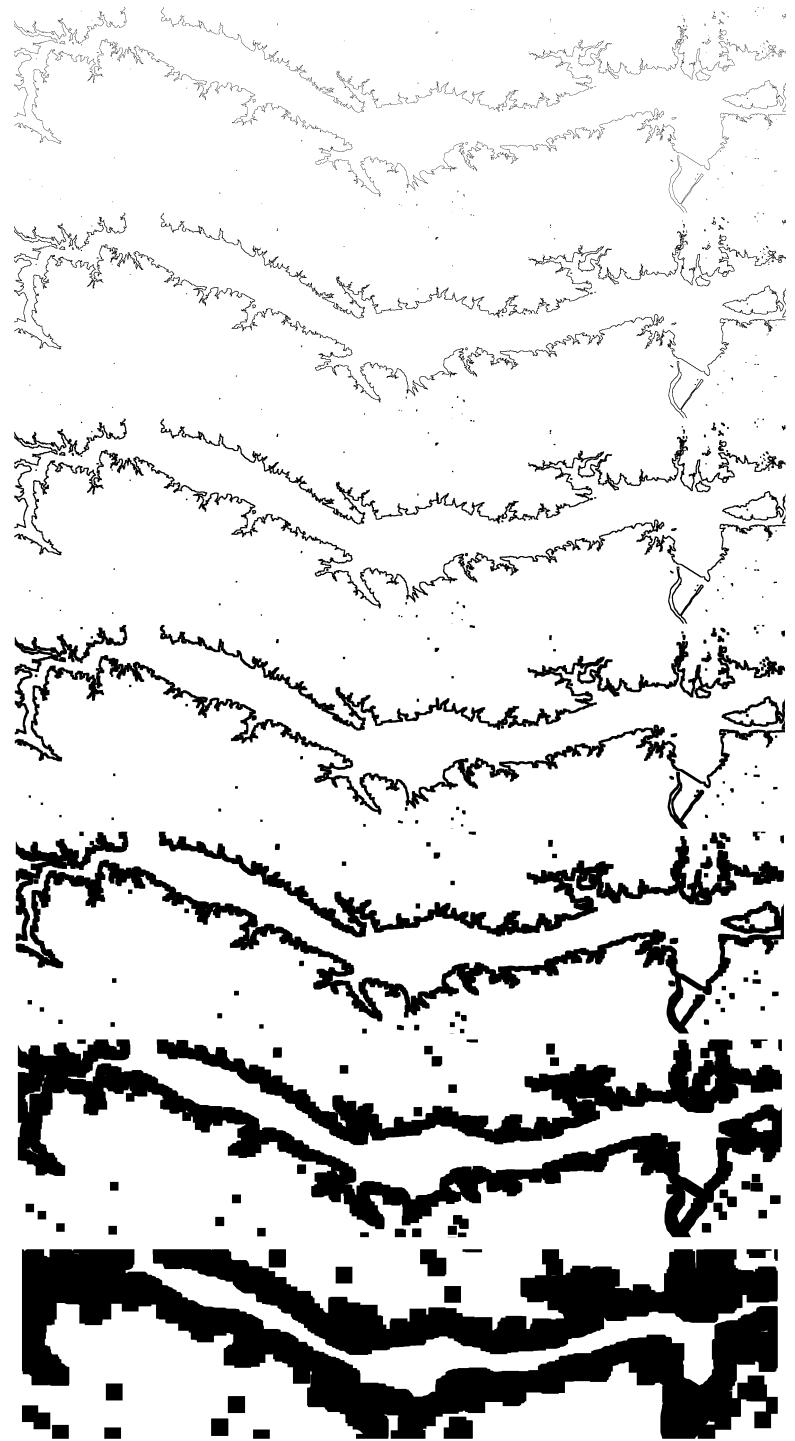
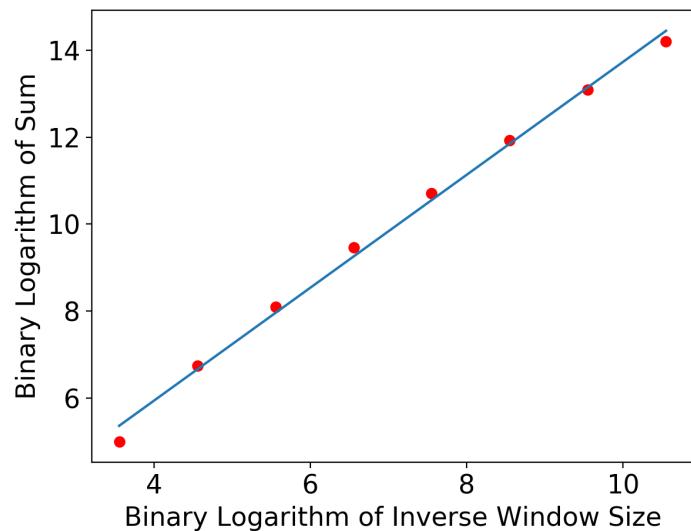


$$\begin{aligned}N &= 6 \\ \varepsilon &= 1/4\end{aligned}$$



Intermediate Steps

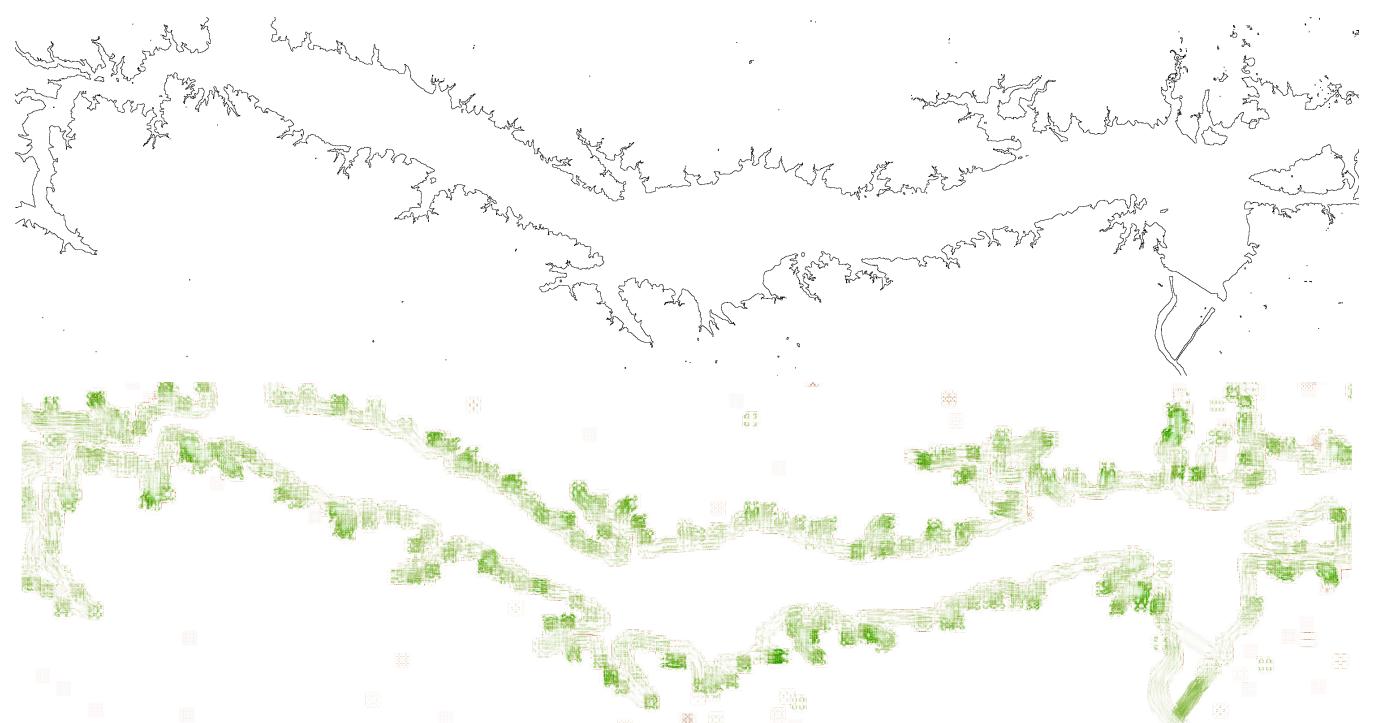
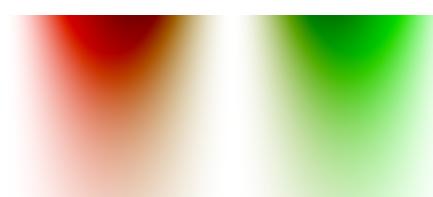
- Right-hand side shows max aggregation
- Sum aggregation for counting them
 - Bridges remaining resolutions
- Only **non-overlapping** windows used in any one regression
- Different overlapping windows used in **multiple shifted** windows
- Each level of max aggregation corresponds to one point in regression for each window



Example Lake Sakakawea

- Only non-integral fractal dimensions shown
- Regression values with large margin suppressed

0 1 2



- Dimensions between 1 and 2 green
- Some prairie potholes show up as red

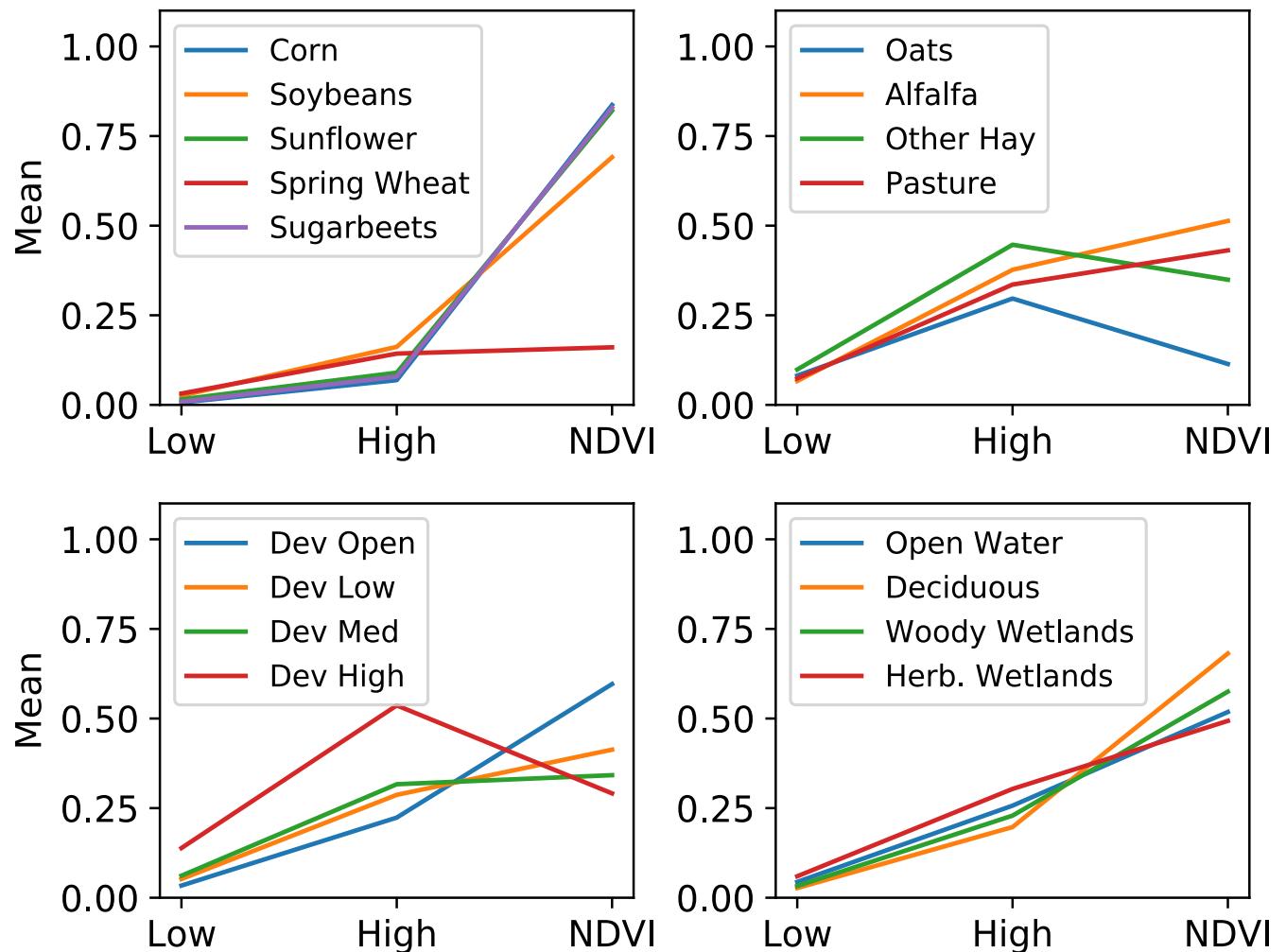
Correlation with Land Use

- Left NDVI with cutoff 0.5
- Middle fractal dimension
- Right non-agricultural land uses

<Image omitted for file size reasons>

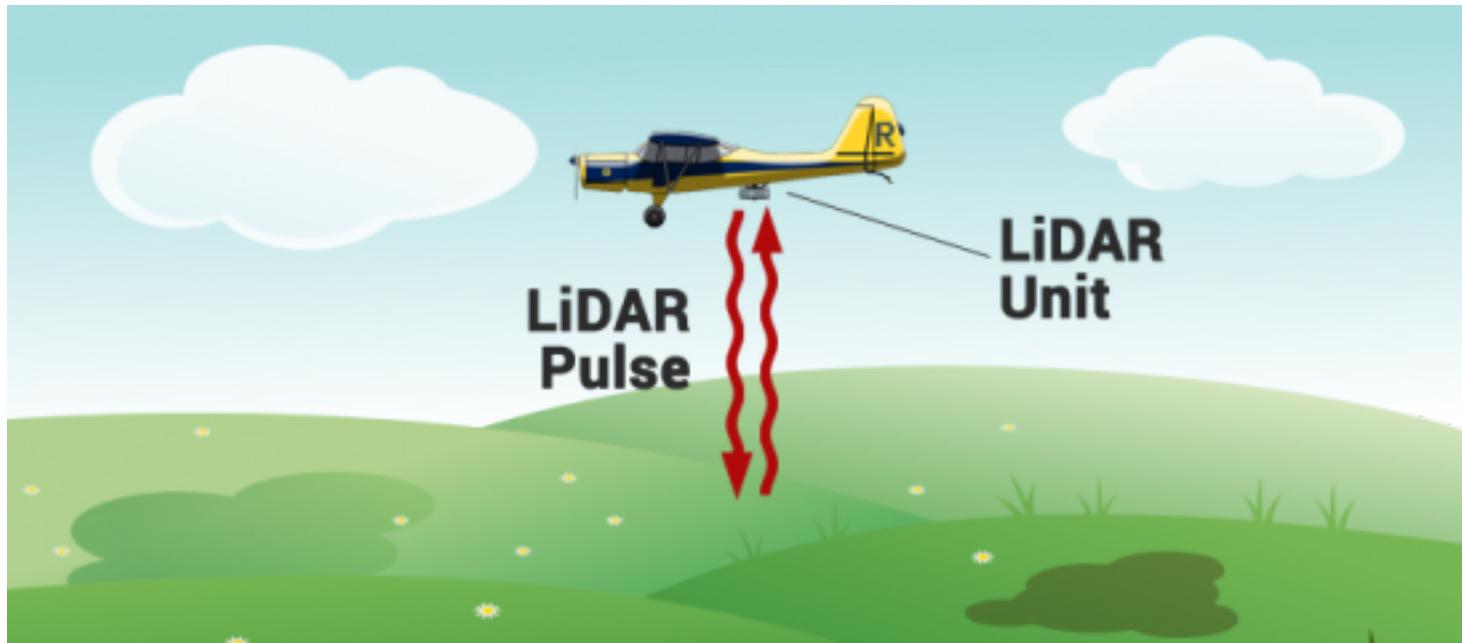
Grouped by Land Use

- Main crop species have low fractality
- Less intense agriculture has higher fractality
- Areas around water high NDVI and fractality between 1 and 2
- Highest fractality in highly developed areas



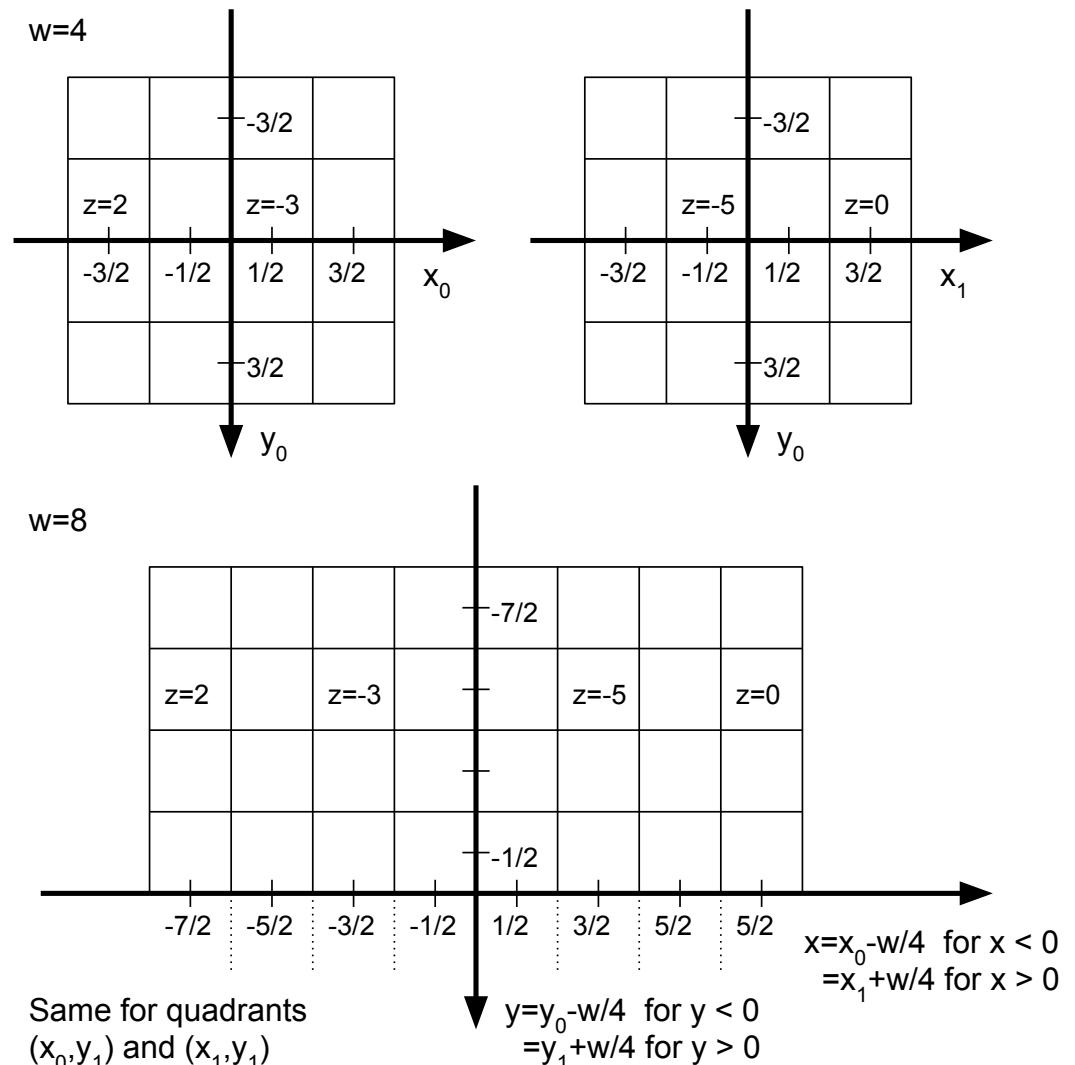
Topography

- Slope and Curvature rely on polynomials of elevation
- 1 m resolution elevation data available from LIDAR measurements
- Existing techniques assume much larger pixels
 - Mostly use 3 x 3 windows
 - Conventionally data rescaled



Additional mathematical challenges

- Now we need aggregates of spatial variables
- Treated as shifting of reference frames
- Curvature also requires higher order aggregates



Coordinate shifts

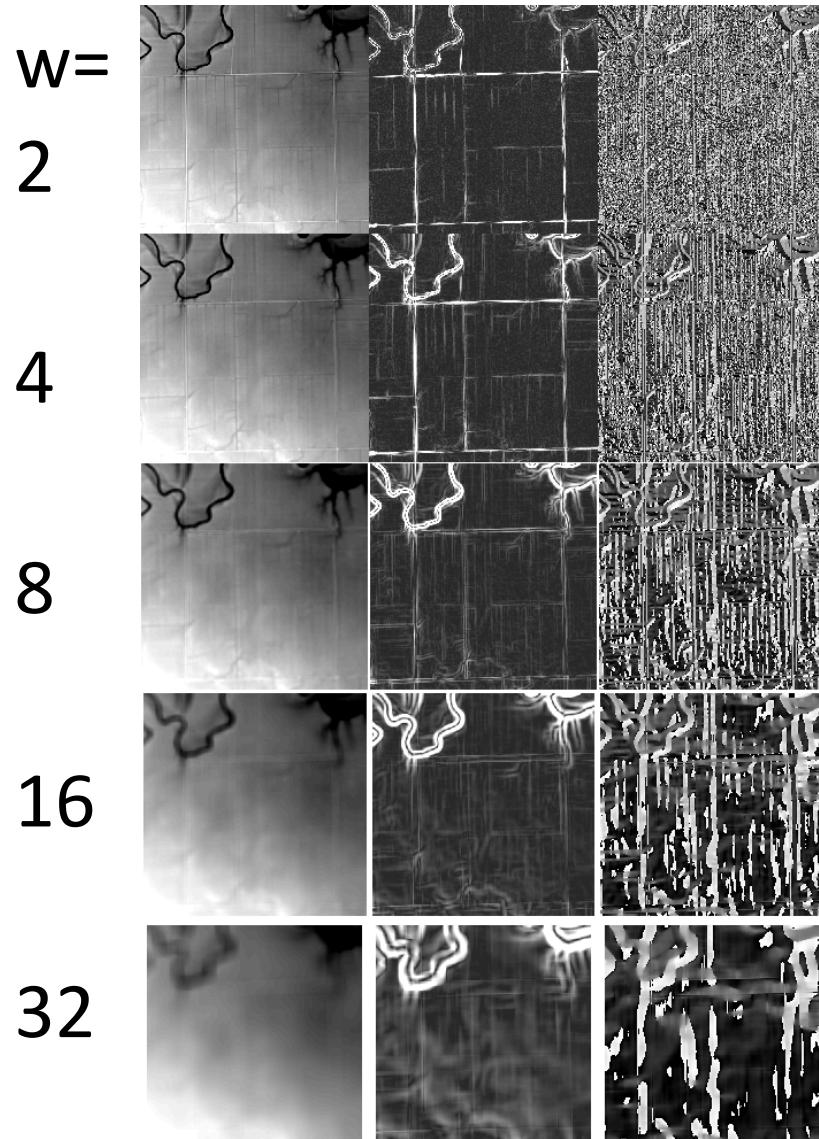
- Averages over spatial dimension x vanish because of symmetry
- Averages over elevation z can be done as previously
- Averages over xz explicitly involve coordinate shifts

$$\begin{aligned}\langle xz \rangle &= \frac{1}{4} \left(\langle \left(x_0 - \frac{w}{4} \right) z_{00} \rangle + \langle \left(x_1 + \frac{w}{4} \right) z_{10} \rangle \right. \\ &\quad \left. + \langle \left(x_0 - \frac{w}{4} \right) z_{01} \rangle + \langle \left(x_1 + \frac{w}{4} \right) z_{11} \rangle \right)\end{aligned}$$

Involves differences between aggregates from previous iteration

$$\begin{aligned}\langle xz \rangle &= \frac{1}{4} (\langle xz \rangle_{00} + \langle xz \rangle_{10} + \langle xz \rangle_{01} + \langle xz \rangle_{11}) \\ &\quad + \frac{w}{4} (\langle z \rangle_{10} + \langle z \rangle_{11} - \langle z \rangle_{00} - \langle z \rangle_{01})\end{aligned}$$

Comparison of elevation, slope, and aspect with ArcGIS results



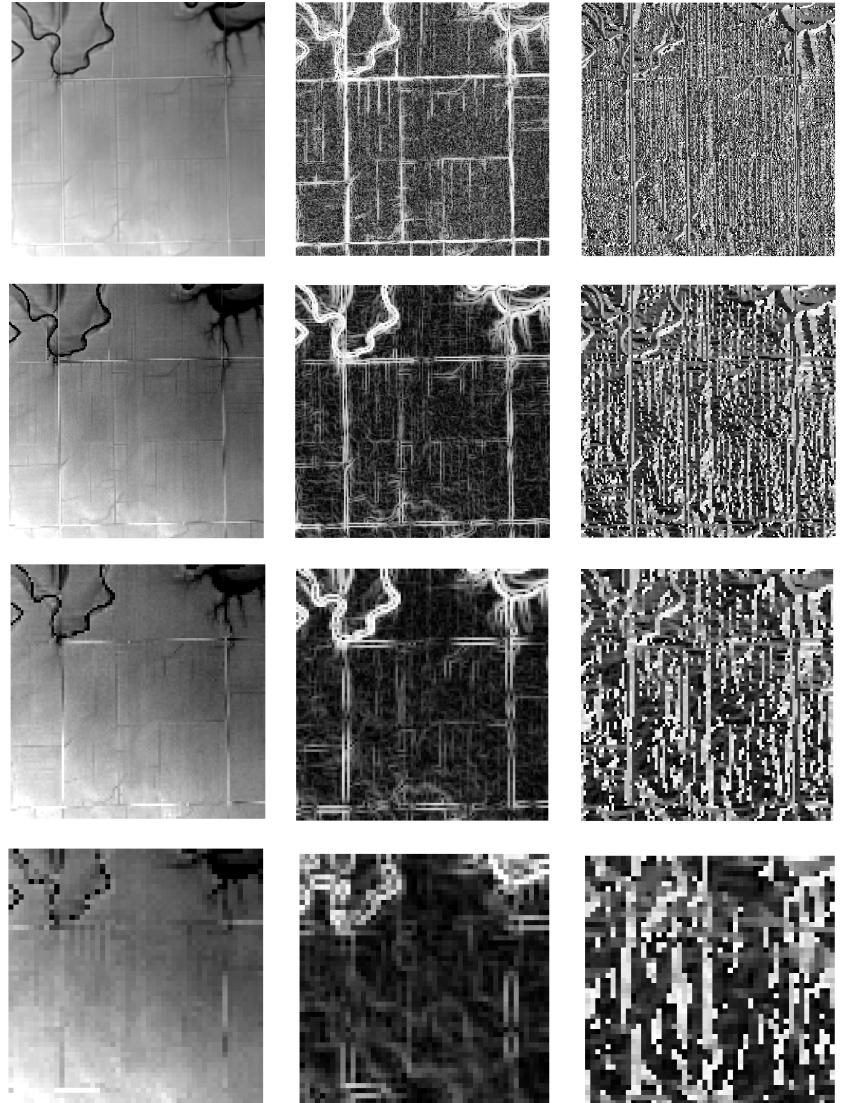
Effec-
tive w

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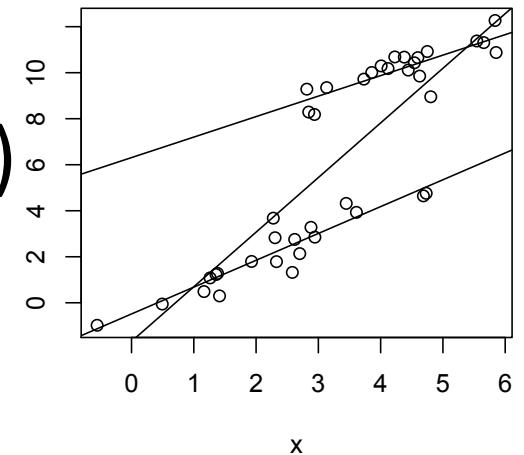
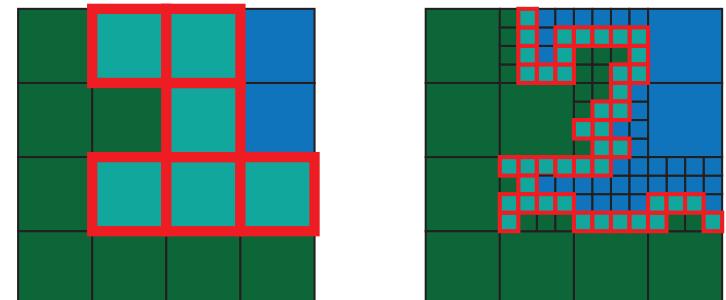
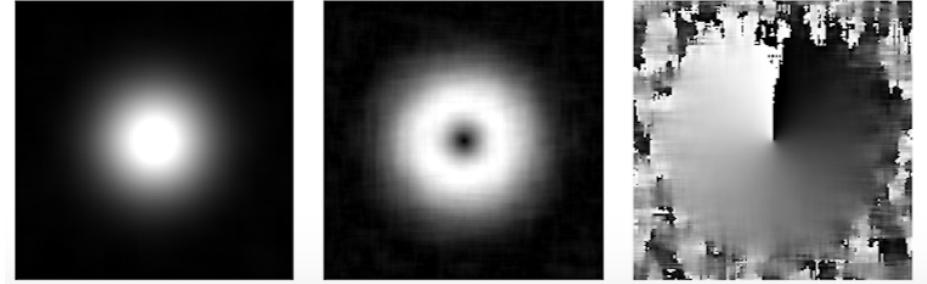
15

30



Plenty to do in this ...

- Topography (Rahul)
- Histograms (Shuhang)
- Wavelets (Mostafa)
- Fractal Dimension (Nick)
- Bit-level processing (Adam)
- Regression (Dawit)
- Deep learning (David, Riley, Jordan)
- ... and other fields (Guy)



Summary

- New remote sensing technology suggest new processing needs / techniques
 - We are only scratching the surface so far
- Linear approaches often go further than expected
- Something that started very practical can created interesting theoretical challenges
 - ... but it takes a while to get there