



National Ecological Observatory Network (NEON)

Soil moisture measurement strategy

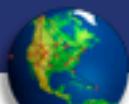
Ed Ayres - Soil Ecologist (eayres@neoninc.org)

Hank Loescher

Hongyan Luo



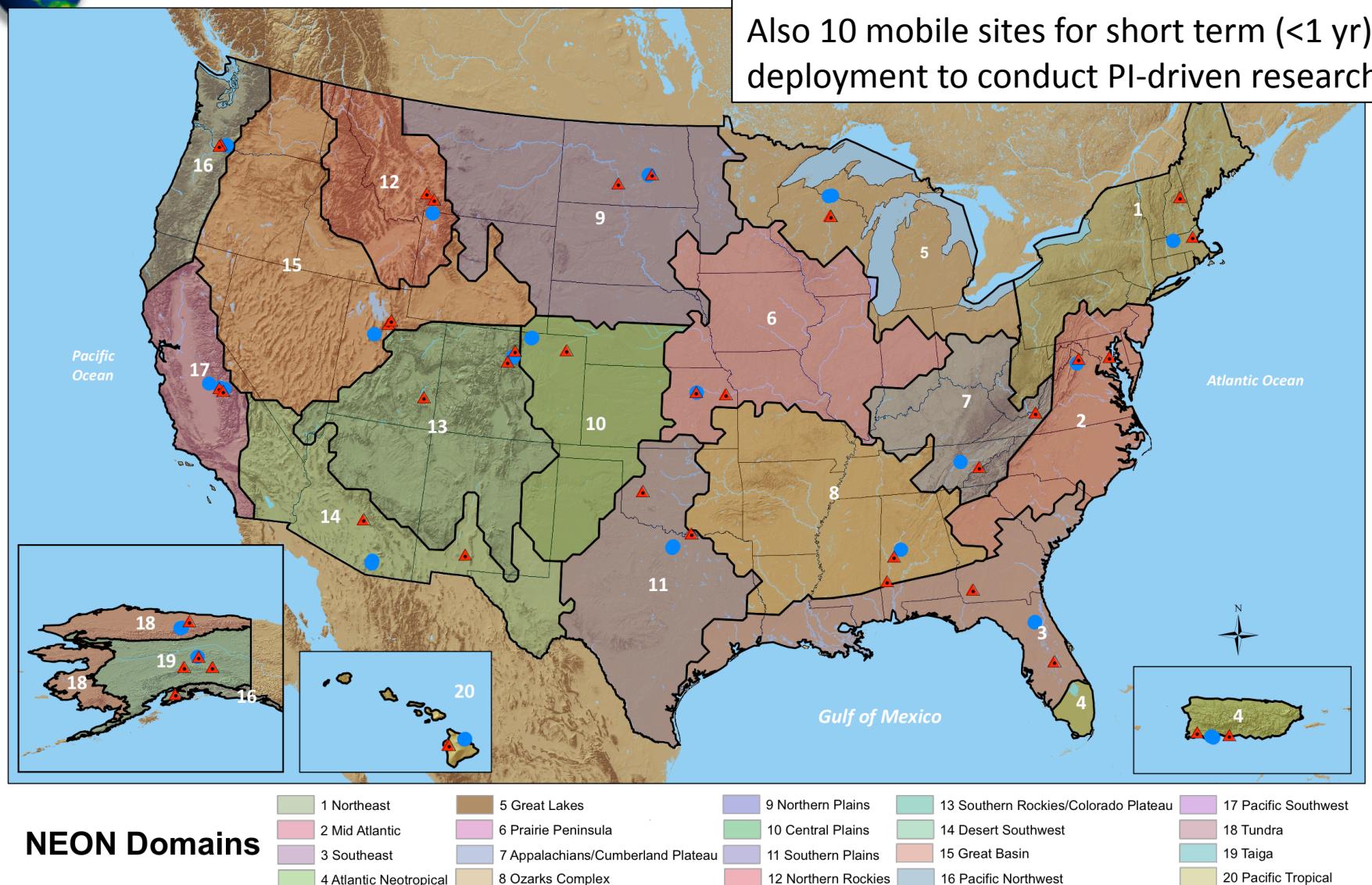
- Project Objective:
 - Enable understanding and forecasting of the impacts of climate change, land-use change and invasive species on continental-scale ecology
 - Measure drivers of change and responses
- Funded by National Science Foundation
- Construction: 2011-2016 (\$434 million)
- Operations: 30 years
- All data will be freely available to everybody



A National Observatory: 20 eco-climatic domains

neon

Also 10 mobile sites for short term (<1 yr) deployment to conduct PI-driven research.



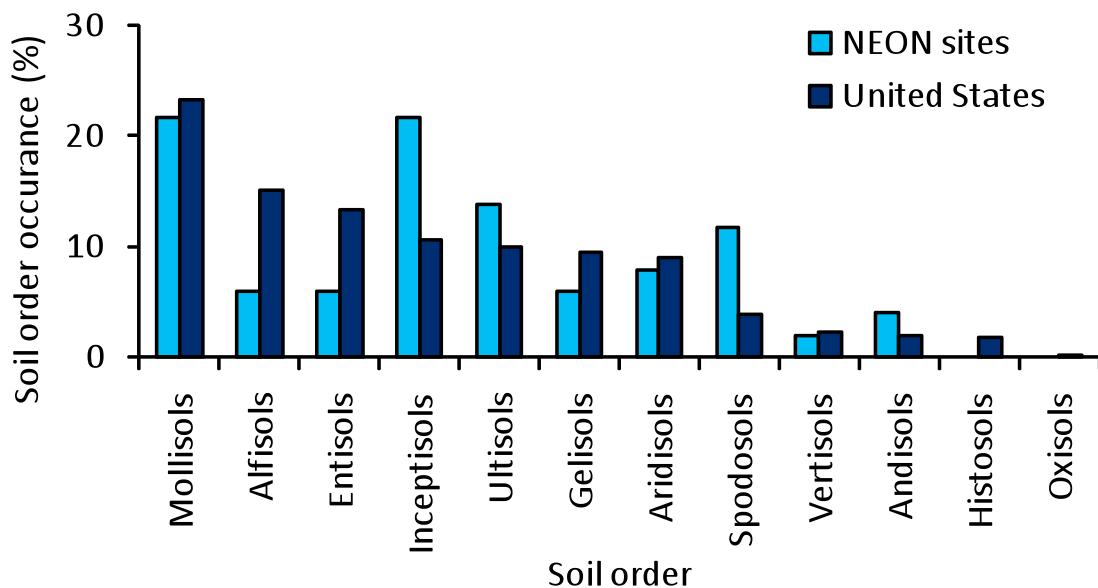
NEON Domains



Representative

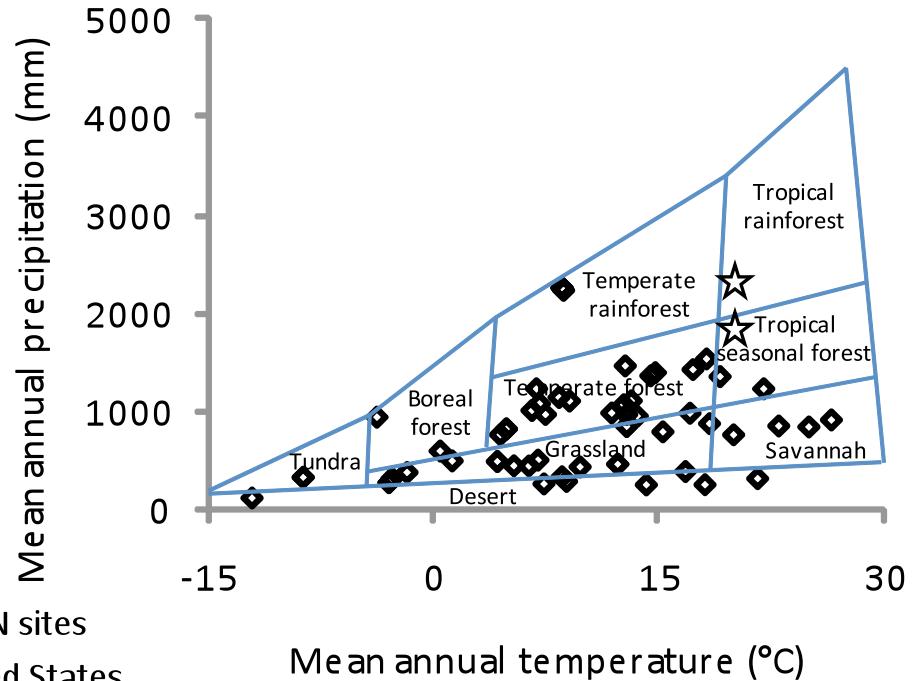
neon

- Includes every major terrestrial ecosystem and soil type in the US



Wednesday, May 18, 2011

SMAP CalVal Workshop #2, Oxnard, CA



Ecosystem boundaries based on Woodward et al. 2004 Phil. Trans. R. Soc. Lond. B 359, 1465-1476.



NEON Measurements

(>500 Level 1 data products)

neon

- **Terrestrial sensors**
 - Physical environment, energy-water-carbon balance, air quality, soil moisture...
- **Terrestrial human-made measurements**
 - Biodiversity, phenology, NPP, infectious diseases...
- **Aquatic sensors & human-made measurements**
 - Biodiversity, phenology, physical environment...
- **Airborne observations (~200-400 km²)**
 - Spectrometer & LIDAR: Vegetation structure and biochemical properties...
- **Maps & Historical Data** (continental scale)
 - Compile existing data, e.g. past/present land-use maps, remote-sensing data, economic/social data...

Terrestrial sensors

neon



- Number of sensors:
 - 14,717
- Number of measurement types:
 - 95
- Data collection frequency
 - 20 Hz to weekly
- Reliability goal:
 - 90% operational time
- Data production:
 - 45 Tb year⁻¹ (raw data)

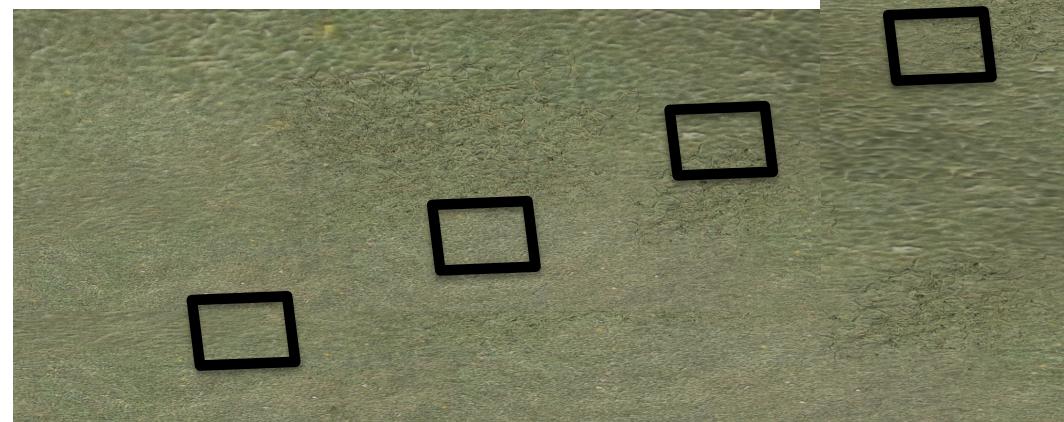
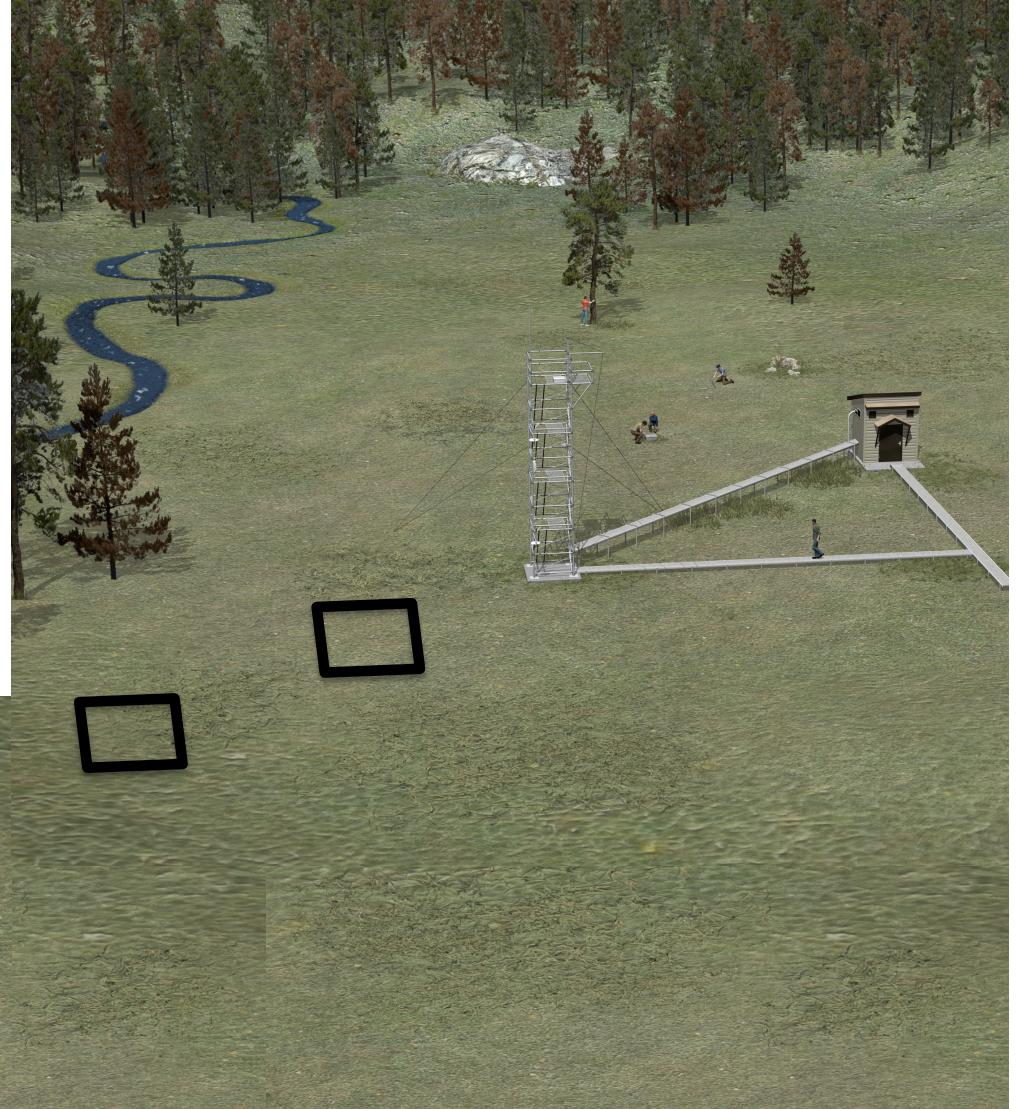


Site design: Terrestrial Sensors

neon



- 1 instrument hut
- 1 tower
- 5 soil plots:
 - 5 x 5 m
 - Within tower airshed
 - On locally dominant soil type
 - Power & communication lines

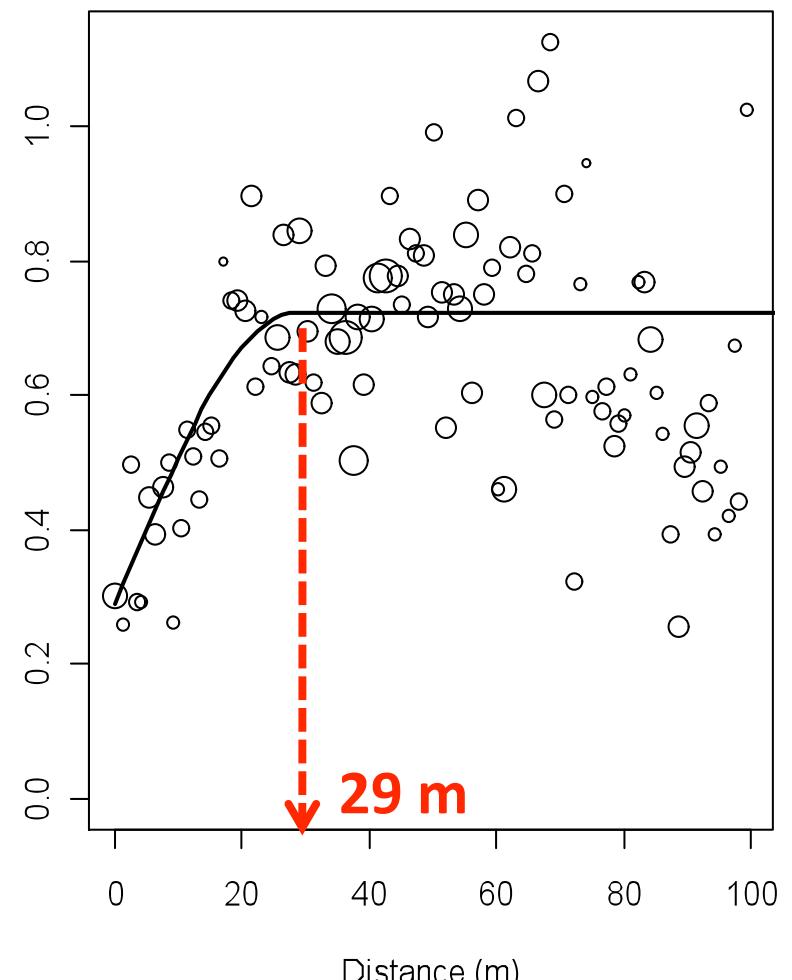
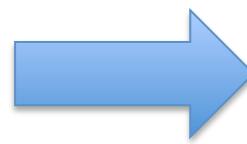
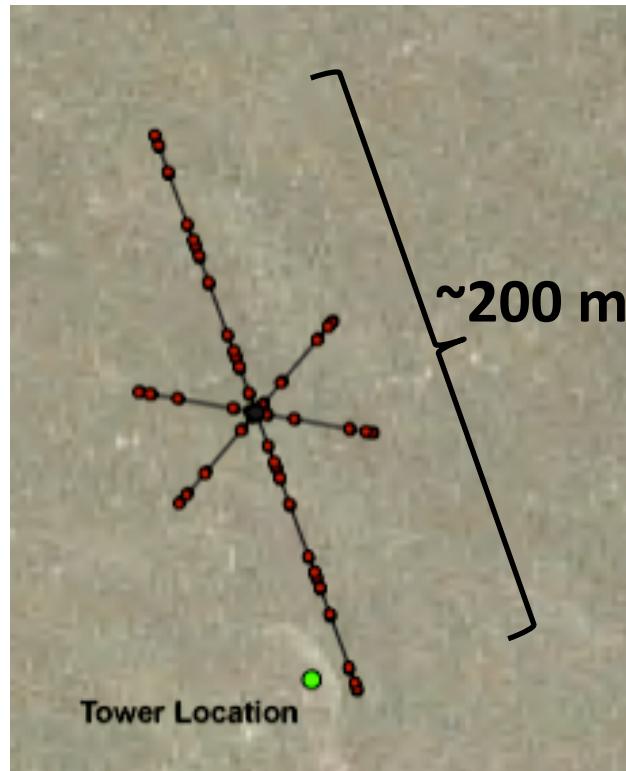


Soil Plot Spacing

neon



- Measured spatial variation in soil moisture & temperature at each site

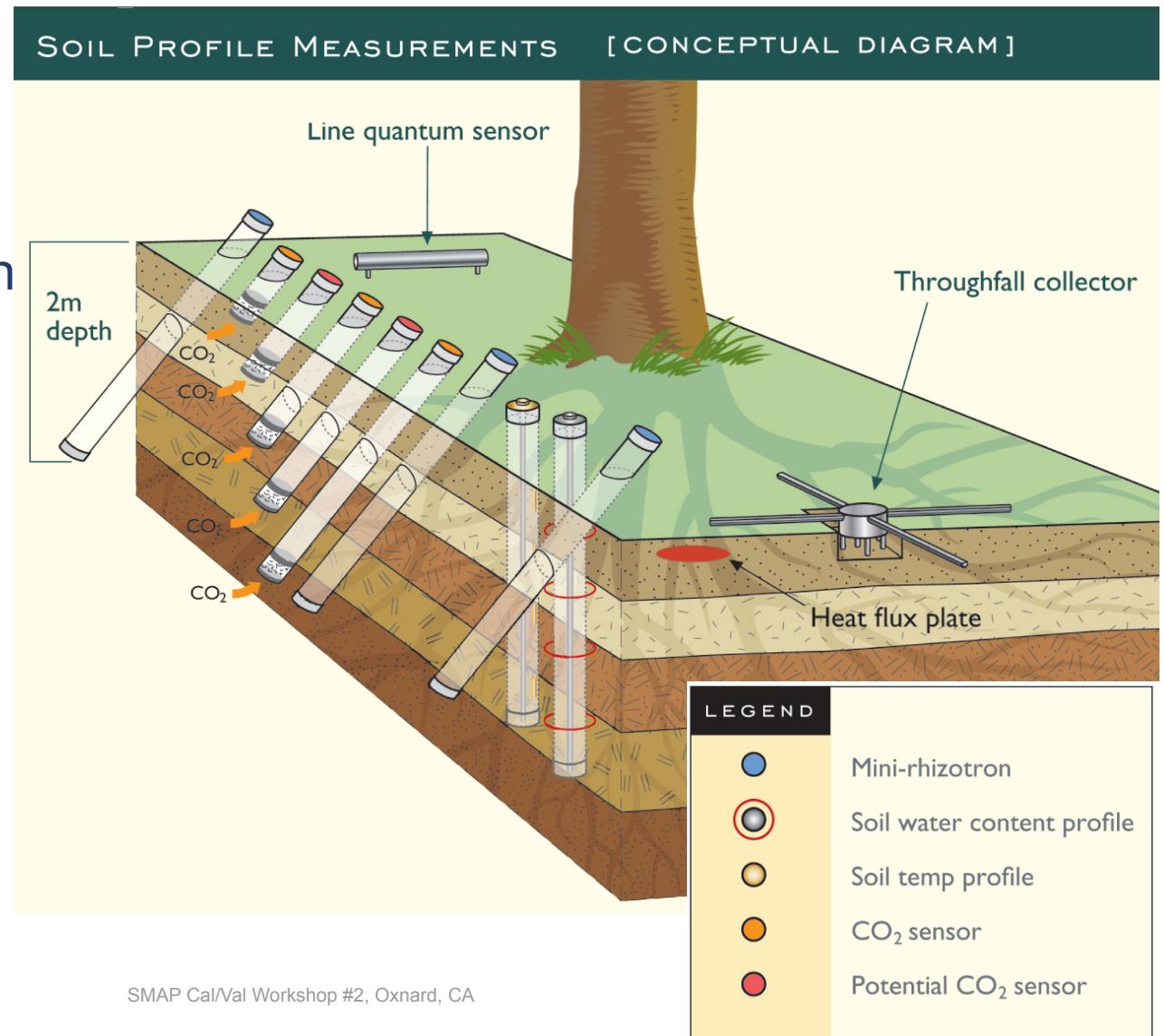


Soil Plot Design

neon



- Sensors up to 2 m deep (3 m if permafrost)
- Placement based on soil horizons and depth
 - 8 soil moisture sensor depths per plot
- Temperature, moisture, and CO₂ sensors located at the same depths whenever possible





Calibration & Validation of Soil Moisture Sensor

neon

- Site-specific and depth-specific calibration
 - Soil collected from each horizon at each site
 - Characterize sensor readings (dielectric constant) over a range of gravimetric soil moisture levels
- Annual validation at NEON Cal/Val lab
 - 2400 soil moisture sensors (excluding replacements)
 - 60 sites x 5 soil plots x 8 depths

Basic (Level 1) Data Products From Soil Plots



| Data Product | Sampling Frequency | Units | Latency of data availability |
|-------------------------|--------------------------------|--------------------------------------|------------------------------|
| Temperature profile | 10 seconds | C | Near real time |
| Water content profile | 10 seconds | m^3 water m^{-3} soil | Near real time |
| CO ₂ profile | 10 seconds | $\mu\text{mol mol}^{-1}$ | Near real time |
| Heat flux | 10 seconds | W m^{-2} | Near real time |
| PAR-line quantum | 10 seconds | $\mu\text{mol s}^{-1} \text{m}^{-2}$ | Near real time |
| Throughfall | NA | mm | Near real time |
| Fine root images | ~2 wk (site & season specific) | Digital image | Near real time |

All raw instrument data (Level 0) & calibrated data (Level 1) will be freely available

Higher (Level 4) soil moisture data products



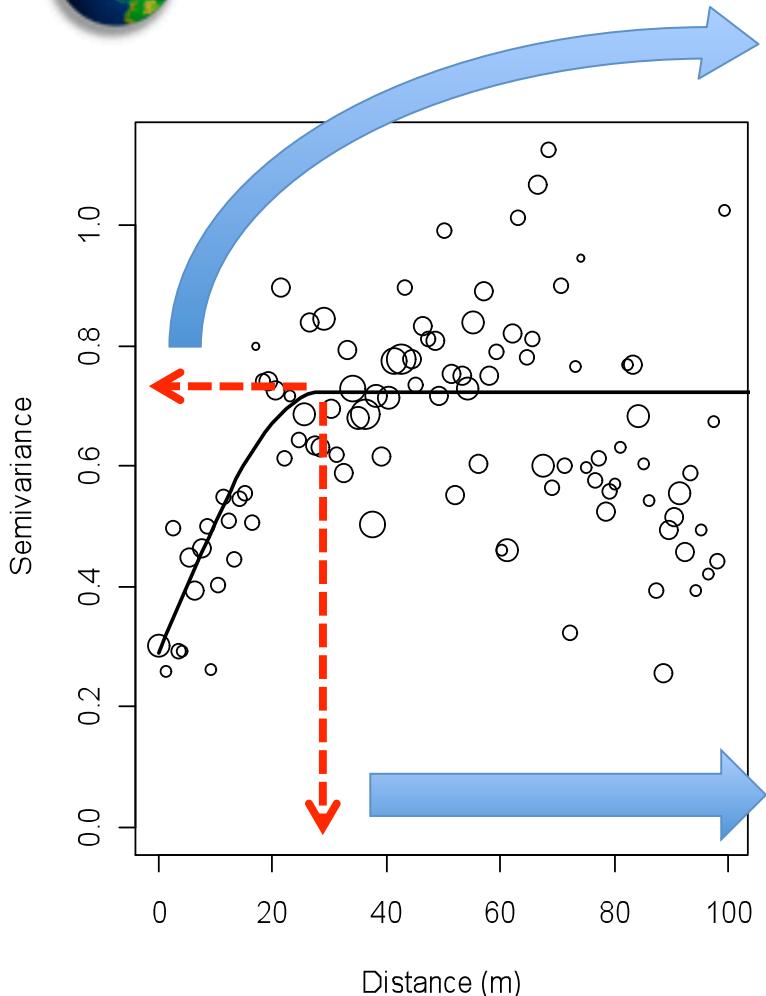
- Soil moisture data available at 3 scales
 - Point measurements (with gap filling)
 - Temporal resolution: 0.5 hours
 - Local scale map (hundreds of meters)
 - Temporal resolution: 0.5 hours
 - Spatial resolution: ~1 m
 - Domain/USA map (thousands of km)
 - Temporal resolution: 24 hours
 - Spatial resolution: ~1 km

Comparison
with SMAP



Spatial variation in soil moisture at local scales

neon



Power analysis

Estimate the number of samples required for a given confidence & accuracy

- Variance = 1.44 (0.72×2)
- Mean volumetric soil moisture = 2.6%
- 95% confidence of being within 5% of mean

= 14 samples

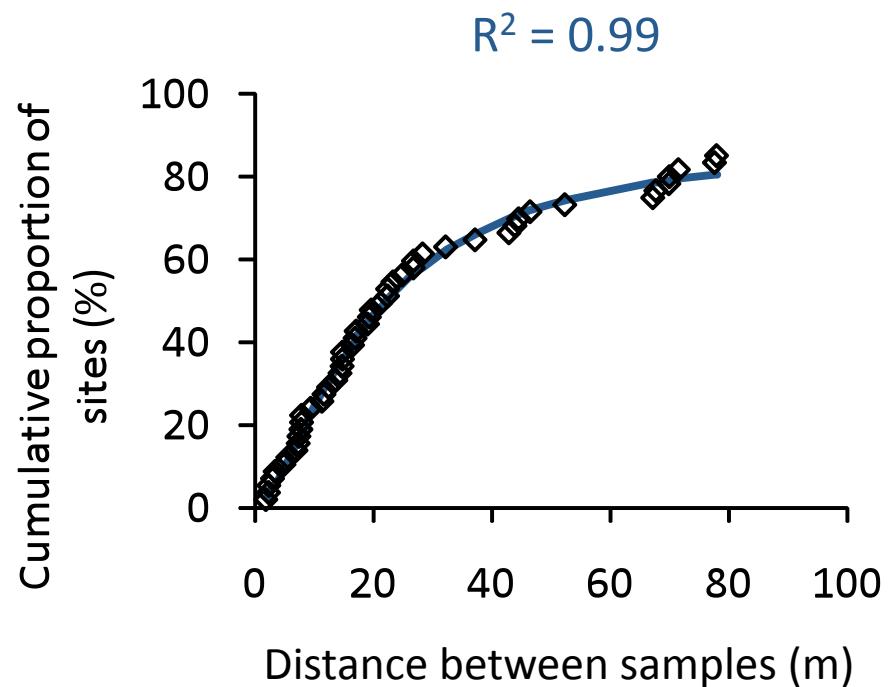
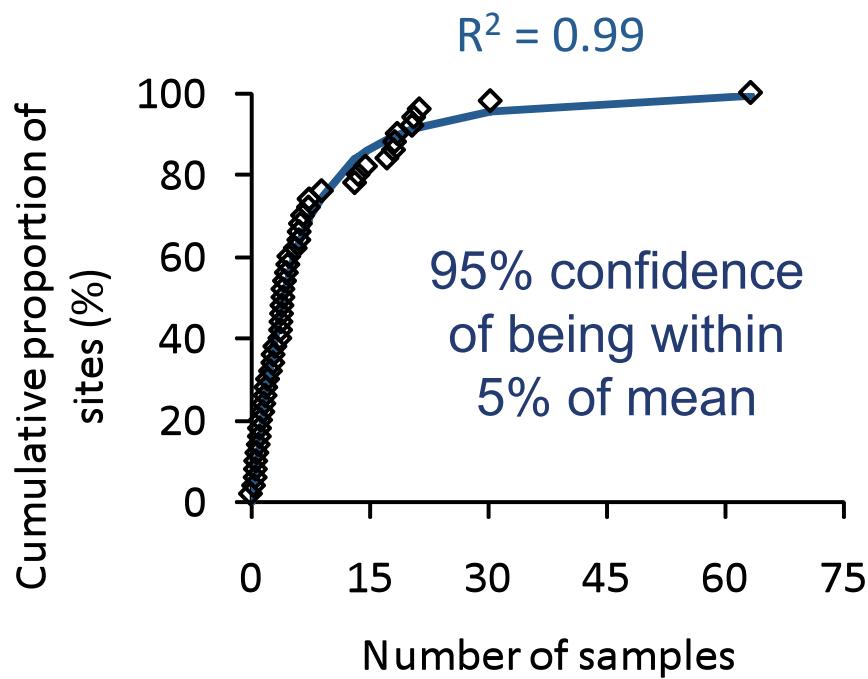
Distance required for samples to be statistically independent at this scale

= 29 meters



Spatial variation in soil moisture at local scales

neon





Sampling designs

95% confidence of being within 5% of mean neon

| | | Distance between samples (m) | | | | | | | | | |
|-------------------|----|------------------------------|----|----|----|----|----|----|----|----|-----|
| | | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| Number of samples | 5 | 13 | 26 | 34 | 38 | 41 | 43 | 45 | 46 | 46 | 47 |
| | 10 | 18 | 36 | 46 | 53 | 57 | 59 | 61 | 63 | 64 | 64 |
| | 15 | 20 | 40 | 52 | 59 | 63 | 66 | 68 | 70 | 71 | 72 |
| | 20 | 21 | 42 | 54 | 62 | 66 | 69 | 72 | 73 | 74 | 75 |
| | 25 | 22 | 43 | 56 | 64 | 68 | 72 | 74 | 75 | 77 | 78 |
| | 30 | 23 | 44 | 57 | 65 | 70 | 73 | 75 | 77 | 78 | 79 |
| | 35 | 23 | 45 | 58 | 66 | 71 | 74 | 76 | 78 | 79 | 80 |
| | 40 | 23 | 45 | 58 | 66 | 71 | 75 | 77 | 79 | 80 | 81 |
| | 45 | 23 | 45 | 59 | 67 | 72 | 75 | 77 | 79 | 80 | 81 |
| | 50 | 23 | 46 | 59 | 67 | 72 | 76 | 78 | 80 | 81 | 82 |
| | 55 | 23 | 46 | 59 | 67 | 72 | 76 | 78 | 80 | 81 | 82 |
| | 60 | 23 | 46 | 59 | 68 | 73 | 76 | 78 | 80 | 82 | 83 |

Designing a Continental Scale Observatory

neon



- Challenges of designing a continental scale observatory:
 - The design must be feasible in widely differing ecosystems and climates
 - It must be scalable at local-, regional-, and continental-scales
 - It must be objective

Acknowledgements & Contact Info



- More info
 - NEON website: www.neoninc.org
 - Ed Ayres: eadyres@neoninc.org
- Acknowledgements
 - Paul Duffy (Neptune Inc)
 - Max Brunke
 - NEON personnel
 - Site hosts
- NSF disclaimer
 - The National Ecological Observatory Network is a project sponsored by the National Science Foundation and managed under cooperative agreement by NEON, Inc. This material is based in part upon work supported by the National Science Foundation under Grant No. DBI-0752017. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Other Terrestrial Sensor Data Products

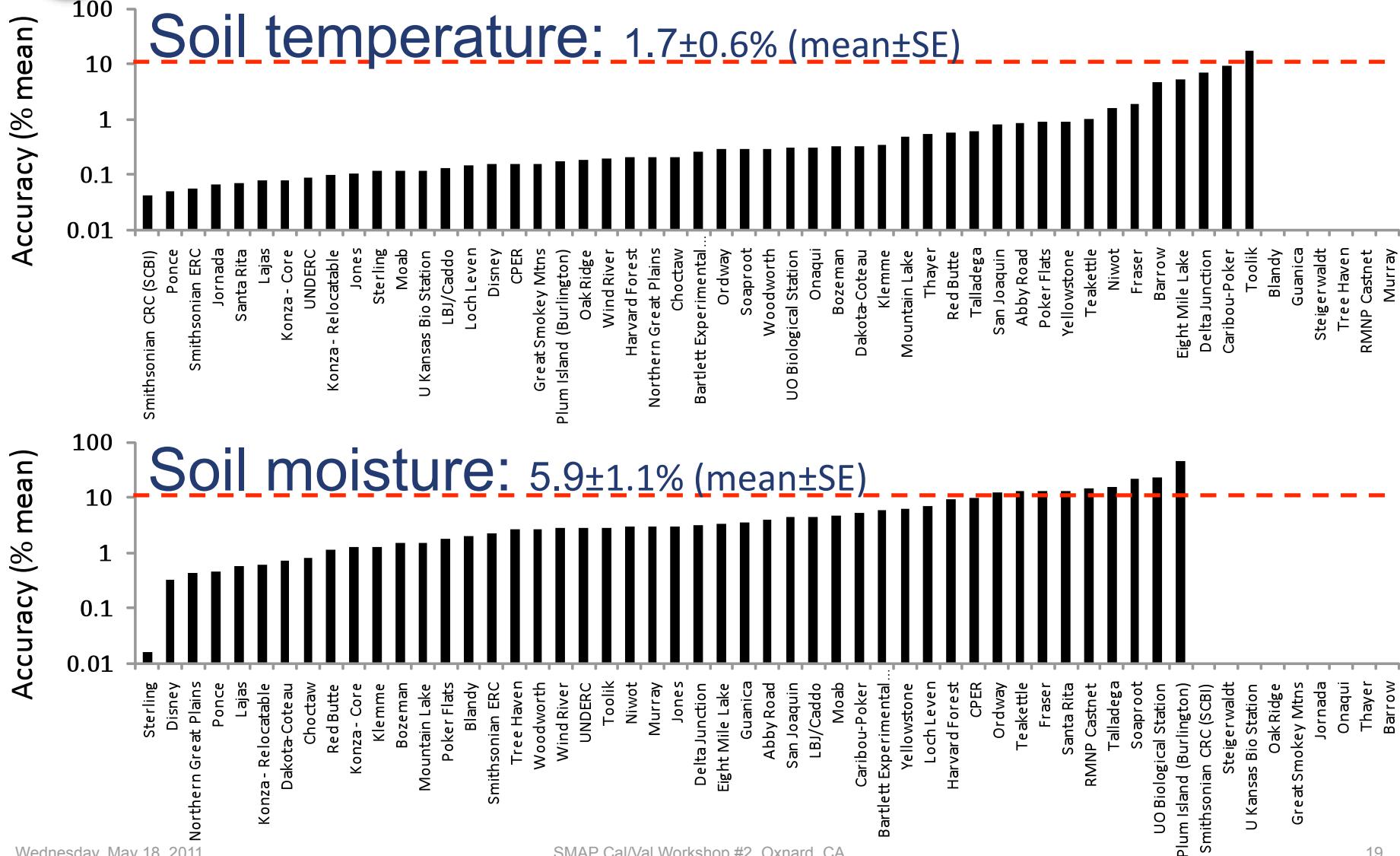


| Location | Measurements | # sensor per site | Sampling freq. | Notes |
|---------------|--|-------------------|----------------|------------------------|
| Tower top | CO ₂ conc. & flux | 1 | 20 Hz | 60 sites |
| | O ₃ conc.& flux | 1 | 1 Hz | 40 sites |
| | NO-NO _y conc.& flux | 1 | 1 Hz | 40 sites |
| | 3D wind speed & direc. | 1 | 20 Hz | 60 sites |
| | Dust (TSP) | 1 | 2 wk | 9 sites |
| | Dust (Particulate) | 1 | 1 Hz | 9 sites |
| | Aerosol depth | 1 | 30 min | 40 sites |
| | Secondary precipitation | 1 | 1 min | 40 sites (Relocatable) |
| | Air temperature | 3 | 1 min | 60 sites |
| | PAR | 2 | 1 min | 60 sites |
| | Direct & Diffused radia. | 1 | 1 min | 60 sites |
| | Pyranometer | 1 | 1 min | 20 site (Core) |
| | Net SW & net LW radia. | 1 | 1 min | 60 sites |
| | Biological temperature | 1 | 1 min | 60 sites |
| | Wet depos. chemistry & precip. isotope | 1 | 2 wk | 40 sites |
| Tower profile | Phenological image | 1 | 4 hours | 60 sites |
| | Air temperature | 4-6 | 1 min | 60 sites |
| | 2D wind speed & direc. | 4-6 | 1 min | 60 sites |
| | Barometric pressure | 1 | 1 min | 60 sites |
| | PAR | 4-6 | 1 min | 60 sites |
| | Biological temperature | 4-6 | 1 min | 60 sites |
| | CO ₂ & C ¹³ conc. | 1 | 1 Hz | 60 sites |
| | H ₂ O vapor & O ¹⁸ & DH ₂ | 1 | 1 Hz | 60 sites |
| Field | Primary Precip. (DFIR) | 1 | 1 Hz | 20 sites (Core) |



Accuracy of spatial soil temperature & moisture estimates (90% confidence)

neon





Sampling designs – Soil temperature

95% confidence of being within 5% of mean

neon

| Number of samples | Distance between samples (m) | | | | | | | | | |
|-------------------|------------------------------|----|----|----|----|----|----|----|----|-----|
| | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| 5 | 25 | 45 | 57 | 64 | 69 | 73 | 75 | 77 | 78 | 80 |
| 10 | 26 | 46 | 57 | 65 | 70 | 73 | 76 | 78 | 79 | 80 |
| 15 | 26 | 46 | 58 | 65 | 70 | 73 | 76 | 78 | 79 | 80 |
| 20 | 26 | 46 | 58 | 65 | 70 | 74 | 76 | 78 | 79 | 81 |
| 25 | 26 | 46 | 58 | 65 | 70 | 74 | 76 | 78 | 79 | 81 |
| 30 | 26 | 46 | 58 | 65 | 70 | 74 | 76 | 78 | 79 | 81 |
| 35 | 26 | 46 | 58 | 65 | 70 | 74 | 76 | 78 | 79 | 81 |
| 40 | 26 | 46 | 58 | 65 | 70 | 74 | 76 | 78 | 79 | 81 |
| 45 | 26 | 46 | 58 | 65 | 70 | 74 | 76 | 78 | 79 | 81 |
| 50 | 26 | 46 | 58 | 65 | 70 | 74 | 76 | 78 | 79 | 81 |
| 55 | 26 | 46 | 58 | 65 | 70 | 74 | 76 | 78 | 79 | 81 |
| 60 | 26 | 46 | 58 | 65 | 70 | 74 | 76 | 78 | 79 | 81 |



Sampling designs – Soil moisture & temp.

95% confidence of being within 5% of mean

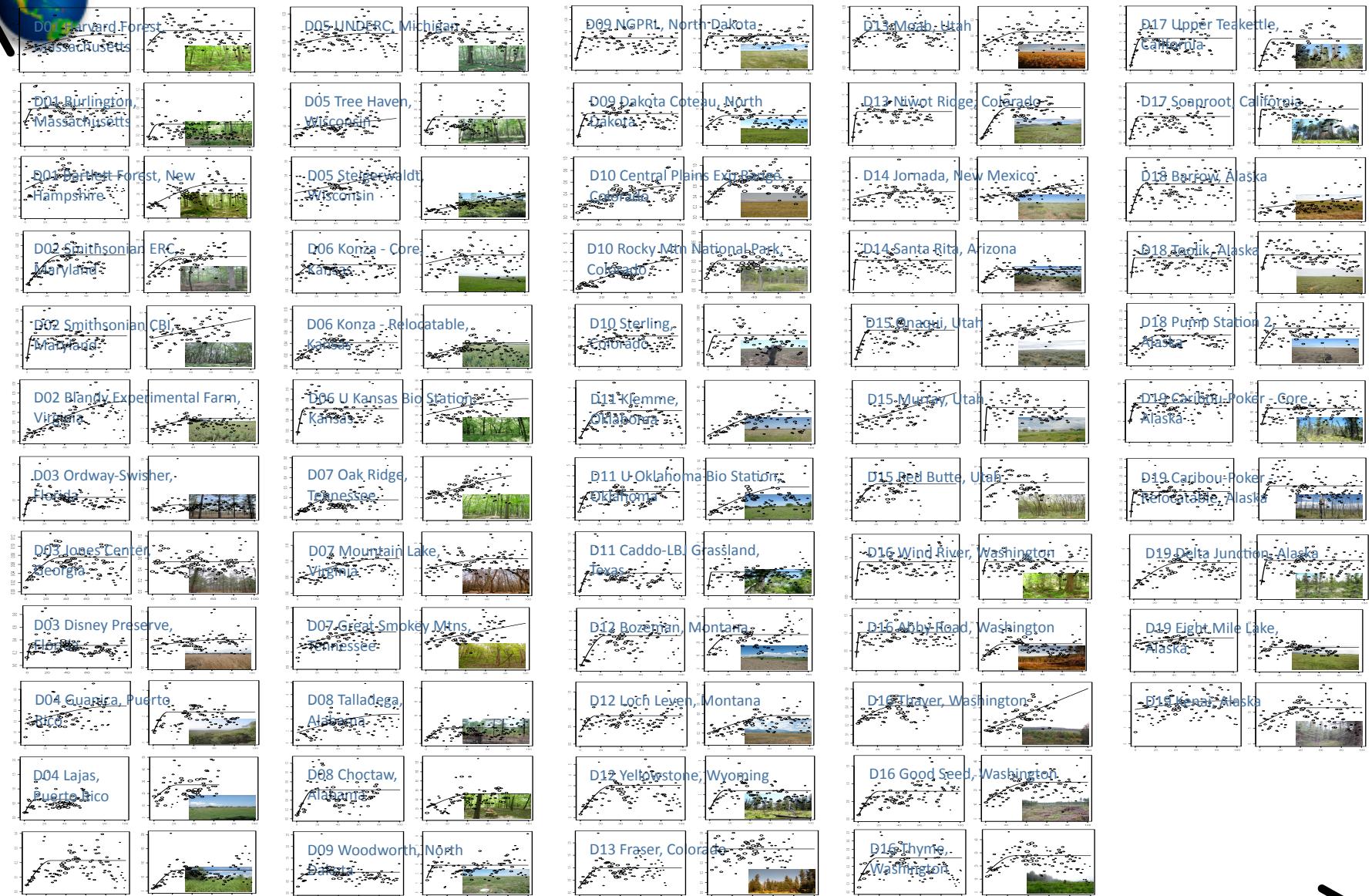
neon

| | | Distance between samples (m) | | | | | | | | | |
|-------------------|----|------------------------------|----|----|----|----|----|----|----|----|-----|
| | | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| Number of samples | 5 | 6 | 13 | 19 | 23 | 27 | 30 | 32 | 34 | 36 | 37 |
| | 10 | 9 | 18 | 26 | 32 | 37 | 41 | 45 | 47 | 50 | 52 |
| | 15 | 10 | 21 | 30 | 37 | 43 | 47 | 51 | 54 | 57 | 59 |
| | 20 | 11 | 22 | 32 | 40 | 46 | 51 | 55 | 59 | 62 | 64 |
| | 25 | 11 | 23 | 33 | 42 | 48 | 54 | 58 | 62 | 65 | 67 |
| | 30 | 12 | 24 | 35 | 43 | 50 | 55 | 60 | 64 | 67 | 69 |
| | 35 | 12 | 25 | 35 | 44 | 51 | 57 | 61 | 65 | 69 | 71 |
| | 40 | 12 | 25 | 36 | 45 | 52 | 58 | 63 | 67 | 70 | 73 |
| | 45 | 12 | 26 | 37 | 46 | 53 | 59 | 64 | 68 | 71 | 74 |
| | 50 | 13 | 26 | 37 | 46 | 54 | 60 | 64 | 68 | 72 | 75 |
| | 55 | 13 | 26 | 38 | 47 | 54 | 60 | 65 | 69 | 73 | 75 |
| | 60 | 13 | 26 | 38 | 47 | 55 | 61 | 66 | 70 | 73 | 76 |

Semivariograms for NEON sites



Semivariance



Site specific sampling design suggestions



neon

- Number of samples required and distance between samples to achieve independence related to site properties including:
 - Soil order
 - Mean annual precipitation
 - Mean soil water content

Site-specific properties



| Number of samples | Distance between samples (m) | | | | | | | | | |
|-------------------|------------------------------|----|----|----|----|----|----|----|----|-----|
| | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| 5 | 13 | 26 | 34 | 38 | 41 | 43 | 45 | 46 | 46 | 47 |
| 10 | 18 | 36 | 46 | 53 | 57 | 59 | 61 | 63 | 64 | 64 |
| 15 | 20 | 40 | 52 | 59 | 63 | 66 | 68 | 70 | 71 | 72 |
| 20 | 21 | 42 | 54 | 62 | 66 | 69 | 72 | 73 | 74 | 75 |
| 25 | 22 | 43 | 56 | 64 | 68 | 72 | 74 | 75 | 77 | 78 |
| 30 | 23 | 44 | 57 | 65 | 70 | 73 | 75 | 77 | 78 | 79 |
| 35 | 23 | 45 | 58 | 66 | 71 | 74 | 76 | 78 | 79 | 80 |
| 40 | 23 | 45 | 58 | 66 | 71 | 75 | 77 | 79 | 80 | 81 |
| 45 | 23 | 45 | 59 | 67 | 72 | 75 | 77 | 79 | 80 | 81 |
| 50 | 23 | 46 | 59 | 67 | 72 | 76 | 78 | 80 | 81 | 82 |
| 55 | 23 | 46 | 59 | 67 | 72 | 76 | 78 | 80 | 81 | 82 |
| 60 | 23 | 46 | 59 | 68 | 73 | 76 | 78 | 80 | 82 | 83 |



Site-specific sampling designs