PROGRESS 2023: CONSTANT-SCALE NATURAL BOUNDARY MAPPING. C. S. Clark[1], M. L. Rilee[2], P. E. Clark[3], [1]Chuck Clark architect, Atlanta GA, rightbasicbuilding@gmail.com, [2]Bayesics LLC, Derwood MD, mike@bayesics.com, [3]Space Science Center, Morehead State University, Morehead KY, p.clark@moreheadstate.edu.

Introduction: Constant-Scale Natural Boundary mapping (CSNB) transforms the surface of any essentially globular object to the 2-D plane in a manner which, unlike conventional projections, preserves proportion and adjacency of natural districts composing the object's surface [1]. When non-Euclidean matters are at play (ice-shell moons, planetary atmospheres, Earth oceanography), CSNB is a powerful and flexible visualization tool, enabling undistorted global observation, at least within a chosen reference frame [2]. With CSNB, once lyrical questions such as *what shape is the ocean?* and *what shape is the atmosphere?* have geometrically sensible answers. [3]. Proof of concept has been amply demonstrated, e.g., [4, 5]. However, as one planetary cartographer put it recently, "Having an automated system that can take a tree and produce a map from it is what it would take for others to see the real value of [CSNB] for their work. The impediment to other people using your maps is, it doesn't just plug into existing mapping software. If new software can make it accessible that should make a big difference" [6].

Product: we report a beginning collaboration with ML Rilee to create CSNB software. Having nudged that snowball a wee bit off stuck, we stepped back and gave this project a general review. We also report:

- on merging Building Information Modeling (BIM) with CSNB to make a new thing we call, shy a better term, Planetary Information Modeling (PIM)
- on insights gained on CSNB formal entities
- a narration of a "turtles & rabbits" method we used to find boundaries in the cosmic microwave background [1, chapter 7], to aid software creation
- preferential dust transport and distribution on comet 67P, as inferred from CSNB maps [4]

Software development: PIM requires a means of harmonizing data of diverse and often irregular spatiotemporal characteristics for integrative analysis. By *harmonize*, we mean a way to organize and store diverse data for efficient search and retrieval scaling in volume, variety, and velocity, without requiring interpolation or homogenization to a common grid.

SpatioTemporal Adaptive Resolution Encoding (STARE) was developed to provide "coordinates" for a universal framework for combining diverse Earth Science data (e.g., Grid, Point, and Swath), including lower-level, non-gridded data [7]. We explore how STARE's adaptability to irregular regions of interest and non-gridded data can be exploited to organize data associated with irregular bodies such as comets.

Based on hierarchical, recursive subdivisions of space and time, STARE coordinates provide both location and neighborhood information (analogous to a street address and zip code) in 64-bit integers. Unlike geohashing mechanisms, STARE exposes the recursive tree-structured coordinate reference system in its integers. Many spatiotemporal set operations, such as intersections and joins, become integer operations, eliminating expensive geometrical floating-point calculations.

Data indexed and partitioned according to STARE can make efficient use of parallel and distributed computing and storage resources, without the limitations of datacubes or legacy native-array-based data formats. STARE adapts to the size and shape of regions of interest and diverse observations that can have radically different spatiotemporal distributions. STARE thus provides a bridge between diverse data and performant computing and storage, including visualization and automating the CSNB process.

In the Earth Science context, just as the ocean has prototopological shape expressible in a time-animated CSNB world map [1, pp. 54–56], so too does the atmosphere. It is now possible to make such a map—we have the data—but the atmosphere changes too fast to make it by hand. We need software to clarify the large-scale patterns of supersynoptic meteorology and climatology. But here, we focus on irregular spatial geometries to elucidate 67P processes.

BIM + CSNB = PIM: No one has yet written an equation for a building, yet we routinely make buildings in computers. Although impossible to write CSNB-map equations, we *can* teach computers to make CSNB, just as we make buildings with computers. Conventional projections can't be shaped to fit necessary situations. And if we can't see the situation, we won't discern the story as quickly as if we had the lights on, so to speak, no matter how many 3D Digital Twins we devote to the problem. The Building Information Model paradigm now revolutionizing architecture—when joined to our novel projection cartography paradigm (CSNB)—also works at planetary scale: the gravity-defined "horizontal" plane (a non-Euclidean surface bounded by a tree) is, in BIM terms, an extractable 2-D plan on which the map's edge functions as a parametric object manifesting critical (or otherwise controlling) circumstances, e.g., stable atmospheric highs or 67P dust concentration extremes.

Formal Entities: In 1942, art historian Erwin Panofsky and mathematician Marston Morse credited

Albrecht Dürer with inventing, in 1522, something they called "prototopology." Our work admits what those three overlooked: the interruption—a tree, which may grow and prune. Result: a continuum of metrical anamorphs, aka CSNB maps, aka interrupted shape models. The tree also generates a continuum of angular anamorphs, only one of which preserves distance (folds to a facsimile of the original solid), e.g., Dürer's cuboctohedron [9]. Both present substantial coding challenges but only metrical variants will interest the map's user. Angular variants, while formally important, serve only to optimize proportions. Metrical variation is key to system's flexibility—the tree prunes or extends—and thereby reflects changing conditions or focus a subject of interest. Metrical variation is how CSNB makes maps that are extremely compact or interrupted, beyond what is possible with conventional methods. We extend our "brick" study [1 pp. 39-41] to its full range of angular and metrical variants, with the belief that formal insights will inform practical applications.

Preferential dust transport and distribution on Comet 67P: Dust, indicated by bright areas on the CSNB maps in Figure 1 and Figure 2, is primarily found in the northern hemisphere due to the orientation of the southern hemisphere toward the sun. Thus, it experiences maximum insolation and water-ice sublimation, followed by release of dust, during perihelion [10]. Dust movement and deposition from south to north apparently occurs both preferentially away from the sun and along paths of least resistance, with lowest relief and elevation at the surface, e.g., following a longitudinal line from south to north, as seen on Figure 1 and Figure 2.

References: [1] Clark PE and Clark CS (2013) "Constant-Scale Natural Boundary Mapping to Reveal Global and Cosmic Processes" *SpringerBrief,* 116 pp. [2], Clark CS and Clark PE (2015) *LPS XLVI* Abstract #1389. [3] Clark CS (2021) *AAG Annual Meeting* Abstract #51869, E-poster. [4] Clark CS and Clark PE (2021) *LPS LII* Abstract #2508 E-poster. [5] Clark PE, Clark CS, Lowman PD (2007) *ISPRS WG-IV/7* LPI 12–13. [6] Stooke PJ (12/26/2023) *pers. comm*. [7] Rilee ML et al. (2021) doi.org/10.1007/s12145-021-00568-8 *Earth Science Informatics*. [8] Panofsky E (1943) *Albrecht Dürer* PUP. [9] Dürer A (1525) *Manual of Measurement* Abaris Books. [10] Wu JS et al. (2017) *MNRAS* 10.1093/mnras/stx332.

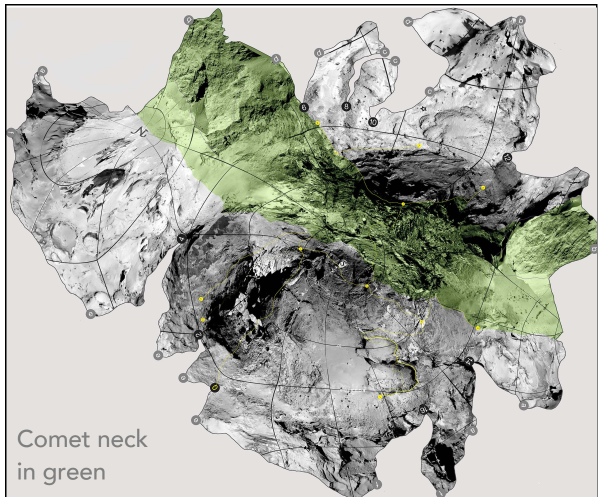

Figure 1: CSNB global map of 67P composed to show dust transport *outward* on the map.

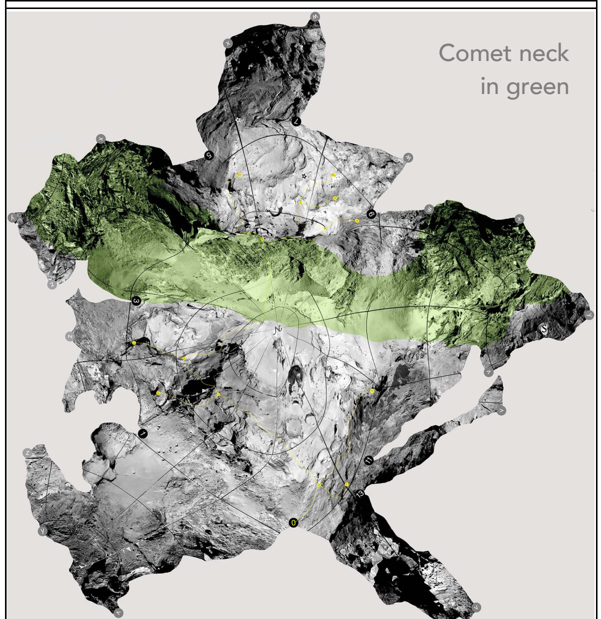

Figure 2: CSNB global map of 67P composed to show dust transport *inward* on the map.