AN ENSEMBLE OF POINT MODELS APPROACH FOR SCIENCE VERIFICATION AND VALIDATION FOR EUROPA CLIPPER'S REASON (RADAR FOR EUROPA ASSESSMENT AND SOUNDING: OCEAN TO NEAR-SURFACE) INVESTIGATION. D. A. Young[1], D. D. Blankenship[1], N. S. Wolfenbarger[1,2], C. Grima[1], K. M. Soderlund[1], K. F. Chan, T. G. Richter, and the REASON Science Team [1]Institute for Geophysics, Jackson School of Geosciences, University of Texas at Austin, TX, USA (duncan@ig.utexas.edu), [2]Department of Geological Sciences, Jackson School of Geosciences, University of Texas at Austin, TX, US

Introduction: The Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON) investigation is the radar sounder, altimeter and reflectometer instrument on NASA's *Europa Clipper* mission. This active dual-frequency (9/60 MHz) instrument is led by the University of Texas Institute for Geophysics (UTIG). The key hypotheses that the REASON team proposed to test are that the ice shell of Europa hosts lenses of liquid water and near surface brines; the ice shell overlies an ocean decoupled from the silicate interior and is subject to tidal flexing; and that the atmosphere, near surface, ice shell and deep ocean participate in exchange essential to the habitability of this moon. REASON was also proposed to support landing site reconnaissance. These hypotheses and goals have been organized as four Guiding Level 2 Data Sets that REASON is responsible for collecting as part of the *Europa Clipper* project (as follows): Shallow Subsurface Structure, Ice Shell Properties, Full Depth Subsurface Exchange, and Local-Scale Surface Properties. REASON Measurement Requirements flow from these data sets and are addressed by the following combination of three baseline measurement techniques: *Sounding* (imaging profiles of the subsurface) [1], *Altimetry* (measuring profiles of the relative topography of the surface) and *Reflectometry* (measuring profiles of the reflective properties of the surface [2]). Two additional measurement techniques (*Ranging* for tidal deformation [3] and *Plasma* [4] for evaluating the state of the ionosphere) are planned but not explicitly required.

Europa's ice shell is a challenging target from the point of view of developing, verifying, and validating these Measurement Requirements. Properties of the ice shell are poorly constrained and continue to be debated. Given the lack of constraints—in particular on the surface roughness at radar wavelengths, volume scattering, and ice shell attenuation—an extremely wide parameter set of possible Europas exist. This includes those that no practical radar system could sound. To ensure that REASON Measurement Requirements are robust, we evaluate these requirements in the context of an ensemble of models for Europa consistent with the range of hypotheses REASON is expected to test [5].

Geophysical regimes: Predictions of Europa's geophysical character tend to be bimodal (e.g., thin versus thick ice shell). To construct models that reflect this bimodality, we define twelve geophysical regimes that describe Europa's environment from its atmosphere to its ocean (Table 1). For each of the twelve geophysical regimes of Europa's environment, we have selected representative parameter values for each of two modes in each regime (e.g., 3 km and 30 km were selected for the ice shell thickness regime; or anti-Jovian/sub-Jovian).

We combine these parameterized regimes to construct point models of Europa that sample the range of published scientific hypotheses and incorporate Europa's known properties.

Regime	Mode 1	Mode 2
Jovian Noise	Sub-Jovian	Anti-Jovian
Ionosphere	No Ionosphere	Mean *Galileo*
Surface Roughness	Ridged Plains	Mottled Terrain
Near-Surface Density	Non-Porous	Porous
Near-Surface Thickness	1 meter	200 meters
Near-Surface Composition	Clean Ice	Brine Filled
Regolith	No Regolith	Deep Regolith
Slab Composition	NaCl	$MgSO_4 \cdot 11H_2O$
Ice-Shell Composition	Marine Ice	Pure Ice
Ice-Shell Thickness	Thin (3 kilometers)	Thick (30 kilometers)
Ice-Water Interface	Water	Eutectic mush
Basal Temperature	270K	250K

Table 1: Geophysical regimes used to construct point models for Europa, employed to evaluate radar performance. The modes of the regimes are intended to either span the observed range of geophysical character, or the range of published hypotheses.

Ensembles of Point Models: These point models are organized into Ensembles of Point Models (EPMs) associated with—but defined independently from—the Level 2 data sets (Figure 1):

- *Shallow Sounding EPM* applies to Sounding measurements in the Shallow Subsurface Structure data set and is evaluated from 400 km spacecraft altitude to closest approach.
- *Full Depth Exchange Sounding EPM* applies to Sounding measurements in the Full Depth Subsurface Exchange data set and is evaluated from 400 km spacecraft altitude to closest approach.
- *Ice-Ocean EPM* applies to Altimetry and Sounding measurements in the Ice Shell Properties data set and is evaluated from 400 km spacecraft altitude for VHF Sounding and from 1000 km spacecraft altitude for VHF Altimetry and HF Sounding to closet approach.
- *Altimetry and Reflectometry EPM* applies to Altimetry and Reflectometry measurements.

Note that the Shallow Sounding, Full Depth Exchange Sounding, and Ice-Ocean EPMs are each constructed for a corresponding data set, although the Altimetry and Reflectometry EPM applies to Altimetry and Reflectometry measurements across all data sets except the Ice Shell Properties data set. This approach is adopted to ensure that the Europa models used to evaluate Measurement Requirements are consistent with the hypotheses and measurement techniques associated with each data set, given that each data set was defined with specific hypothesis tests in mind. In particular these hypotheses relate the structure and properties of Europa to a particular mode for each regime (Table 1) as well as their combinations with other regimes/modes to form an EPM (Figure 1). As a result of this approach, a single Measurement Requirement may be evaluated using multiple point models because the requirement traces up to multiple Level 2 data sets.

Additionally, the EPMs to validate REASON's Measurement Requirements are suitable for "*characterizing*" and "*searching*" (where applicable) as required at Level 2. For each applicable individual Measurement Requirement, we evaluate signal losses within each point model given the required instrument performance to evaluate what observables will be successfully measured. Where a Measurement Requirement traces up to a Level 2 requirement which involves *characterizing* a property of Europa, the requirement must be met for a majority of point models in the selected Ensemble to "valid" the REASON instruments; but for *searching*, the requirement needs be met for only one of the point models in the Ensemble.

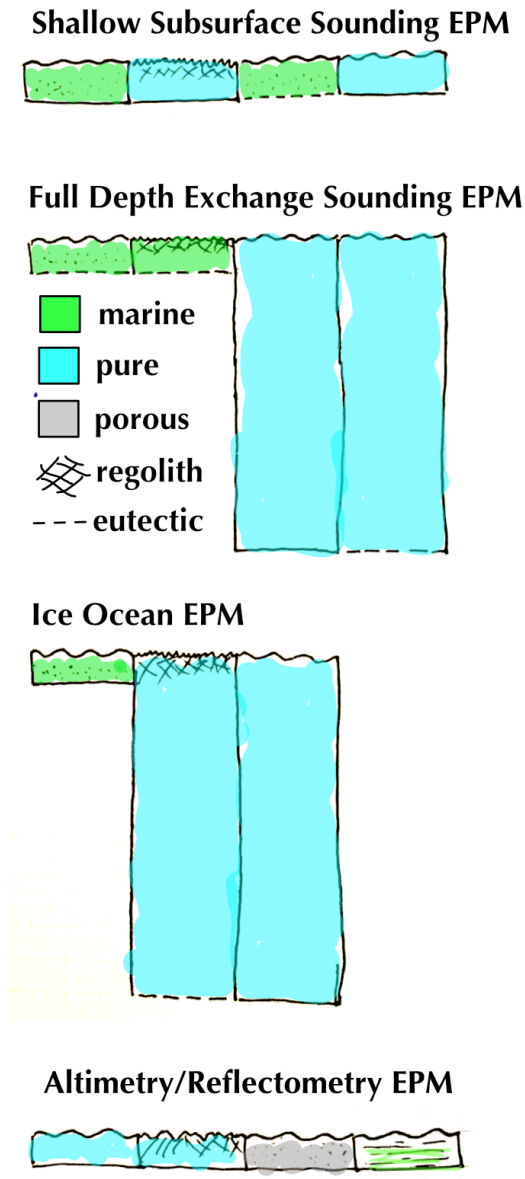

Figure 1. Graphical representation of the geophysical stacks of regimes used to create the Ensembles of Point Models (EPMs) used to evaluate REASON Level 2 science; each point model has a Sub-Jovian and Anti-Jovian version, which differ due to Jovian noise a frequencies below 42 MHz, doubling the number of point models shown here. The point models represent combinations of the Geophysical Regimes/modes in Table 1.

References: [1] Blankenship et al., 2009, *Europa* **[2]** Grima et al., 2014, *PSS* **[3]** Steinbrügge et al., 2018 EPSL **[4]** Scanlan et al., 2019, PSS **[5]** Young et al., in prep, JPL IOM-REASON-2017-001.