**APPENDIX – ESTIMATION OF TOUCHDOWN AND LIFT-OFF TIMES**

* Touch down and lift off times for each survey tow were estimated from tilt angle data, as measured by a Star Oddi DST tilt probe encased in a stainless steel arm attached directly on the trawl footrope.
* Survey catches are standardized with respect to surface area swept by the trawl.
* Swept area for each tow is calculated using trawl width measurements from trawl acoustic sensors, position or speed information from the survey vessel, plus time bounds which specify when trawling starts and ends.
* For our purposes, we assume the start time to be coincident with the time that the trawl touches down, which is estimated from tilt-angle probe data from the attached footrope mechanism.
* The trawl end time for the active trawling phase is defined by the time when winching of the trawl net is initiated and deceleration of the survey vessel begins.
* The bounds of the passive trawling phase are defined by the stop time and the time at which the trawl lifts off the sea bottom, as estimated from tilt-probe data.
* Tilt angle data within different trawling phases, say the descent and bottom trawling phases, have different trends and levels of variability.
* A switch-point model was applied to model these features, in particular the time that the transition between trawling phases occurs, i.e. the touchdown and lift-off times.
* The switch-point models had the following form:
* A piecewise linear model with smoothed transitions was used to model the tilt angles during the descent, bottom and ascent phases of trawling, as well as the transition periods between each phase.
* Let , and represent the linear rates of angular change for the descent, bottom and ascent phases, respectively.
* The touch down event designates the time which separates the descent and trawling phase and the lift off event designates the time separating the trawling and ascent phase.
* We allow for gradual transitions between each phase by defining transition functions defined over the time intervals and for the touchdown transition and and for the liftoff transition.
* We define a linear-quadratic-linear kernel function as:
* This function is linear (i.e. zero constant) for values of , becomes quadratic in the domain , then becomes linear again for .
* It also has smooth first-order derivatives at its transition points, and .

We then allow for gradual transitions to occur over time intervals centered on these for the touch down and for the lift off. This leads to a set of four transition times: and for the touch down period, and and for the lift off period.

These transition times divide the tilt angle time series into five phases: the descent phase for , the transition to the bottom phase for , the trawling phase for , the transition to the ascent phase for and the ascent phase for .

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Phase** | **Lower bound** | **Upper bound** | **Function** | **Polynomial** |
| Descent | - |  |  |  |
| Touchdown |  |  |  |  |
| Trawling |  |  |  |  |
| Liftoff |  |  |  |  |
| Ascent |  | - |  |  |