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Supplementary material for

Transcontinental pathways and seasonal movements of an Asian migrant, the Common Ringed Plover *Charadrius hiaticula tundrae*

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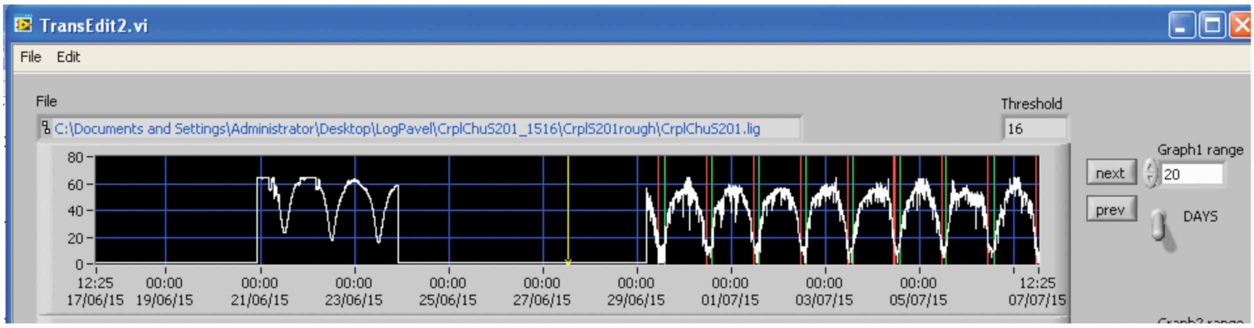
This PDF contains:

Supplementary methods for geolocator analysis.

GEOLOCATOR CALIBRATION AND POSITIONAL ERROR ESTIMATION

Geolocators No. 869 and 870 received good calibration near Philadelphia (40.1 N). The calibration for these was stationary lasting longer than 30 fixes, with careful notation of weather shading at dusk and dawn and including at least one fix during perfectly clear weather (Porter & Smith 2013). For the other three (No. 200, 201, and 204), calibration in Chukotka (62.5°N) was not possible as the light signal was too far north and the selected threshold of 16 did not intersect the light curve (i.e. no total darkness was attained at this time of the year as twilight in Chukotka does not reach zero). The image below shows the signal recorded by geolocator 201 'off the bird' (i.e. before deployment), for three nights between 21 Jun 2015 and 24 Jun 2015.



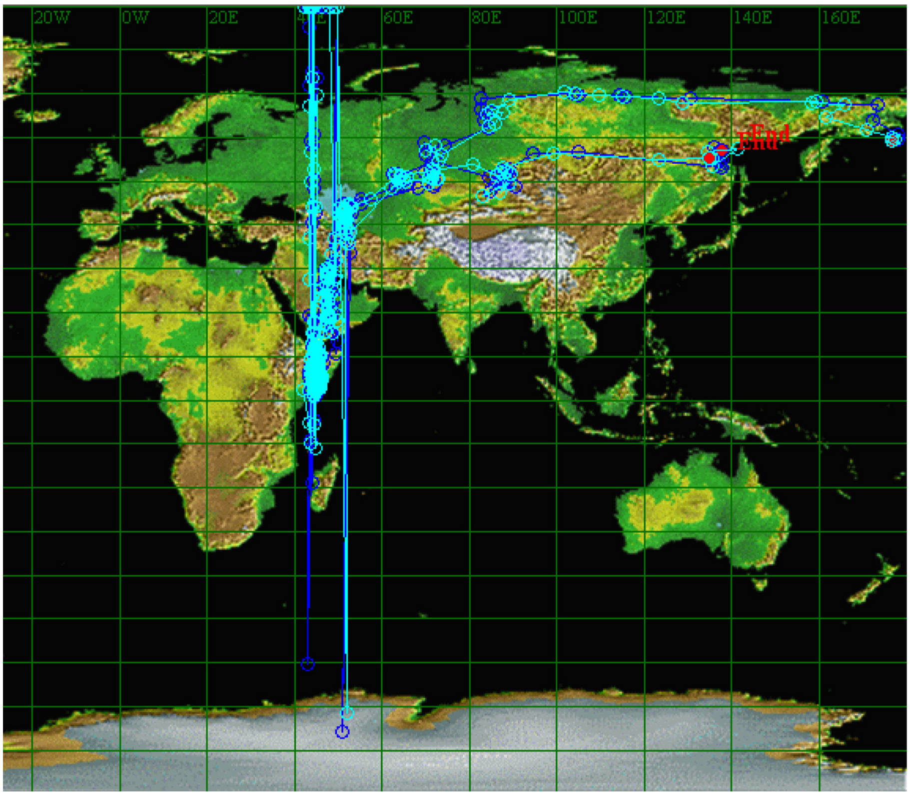
Once it was put 'on the bird' (on the 29 Jun 2015) the shadow of the bird (plus terrain, habits, etc.) likely made the signal intersect at threshold 16 (thus the red and green lines which correspond to the recorded times of sunrise and sunset). However, bird shading dislocated fixes southward from the true position in Chukotka by 70, 150 and 160 km for the well-calibrated geolocators (869 and 870). The option of raising the threshold to 25 in order to intercept the Chukotka light curve was considered and rejected, as setting the threshold 25 resulted in fix dislocations due to weather shading that were large.

An alternative way to deal with uncalibrated geos is to balance the track on places where the conductivity sensor indicates a salt water signal, and assume the bird is at the intersection of the average longitude and the closest coastline (Porter & Smith 2013). This was possible for all three uncalibrated geolocators (No. 200, 201, and 204), at the wintering areas and at the Caspian Sea (which is a salt water body). Shading during dusk and dawn would affect such fixes, and such shading was unknown. However, for the wintering locations the record is sufficiently long to assume at least some clear days were included.

Finally, for consistency it was decided to set sun elevation angle to –5.1 for the uncalibrated geolocators, as attained in the calibrations of geolocators No. 869 and 870, and the potential errors were explored by setting the sun elevation angle to the likely minimum and maximum for cluster edge analysis (Porter & Smith 2013). Examination of 18 geolocators that received stationary calibration near Philadelphia produced the range –4.5 to –5.2 (RP pers. obs.). This range results from both sensor variation and the small difference in atmospheric clarity even among 'very clear' days. The change of sun elevation from –4.5 to –5.2 resulted in a change in latitude for the Chukotka datasets that ranged between 70 and 380 km. The smaller error was in the high latitudes, and grew larger at lower latitudes.

The latitudinal error of the well calibrated geos (No. 869 & 870) in Chukotka equated to 70 and 160 km using sun elevation –5.1 and –5.0. The three uncalibrated geolocators (No. 200, 201 and 204) were therefore analyzed using –5.1. If the true sun elevation angle should have been –4.6, then during migration and in bad weather conditions, latitudinal error could equate to 540 km. Wintering areas locations benefited from hundreds of fixes, and equinox equidistance calculation (Porter & Smith 2013) that greatly increased the wintering area precision.

Although maximum positional error of 540 km seems large, the conclusions of this paper are at the continental scale, and would not be changed by errors in sun elevation. The figure below shows the raw data from geolocator 204 (one of the three uncalibrated geolocators), using sun elevation angle of –5.1, clearly displaying the loop migration pattern (which was clear for all five geolocators).

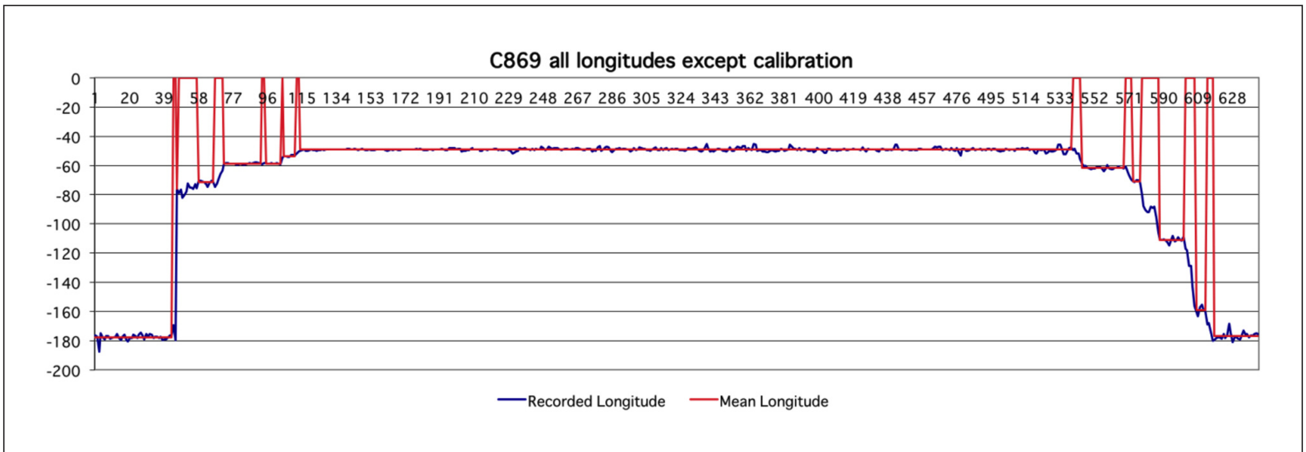


LATITUDE AND LONGITUDE ANALYSES

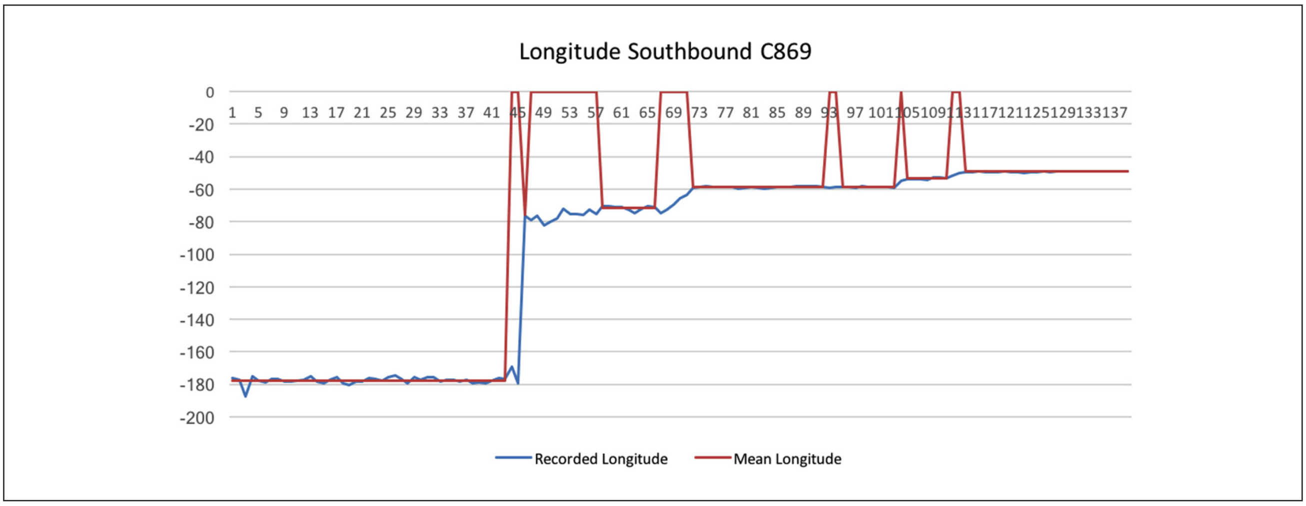
Longitude

As the main guide of the analysis, many longitude plots were built for each geolocator.

Below is a typical annual chart where the red line indicates the mean longitude for stationary periods (i.e. the mean longitude for each stationary period is constant). This is similar to the recorded longitude for stationary periods, but between these stationary periods, when the bird is in flight or steady passage, mean longitude becomes zero and the red line is set to that value by the user (i.e. a period when no average was calculated).



Subsequently, charts were built for specific periods (southbound migration, wintering, northbound migration) and examined for problems with the fixes. Only rarely (nearly never), a fix was deleted from the longitude mean. The plot below allows determining periods of steady passage, and migration onset and stop dates. Movements directly north or south are not visible since longitude is unchanging. For such north/south movements, fix latitude, minimum and maximum recorded temperatures, and conductivity parameters must be consulted in order to identify them.

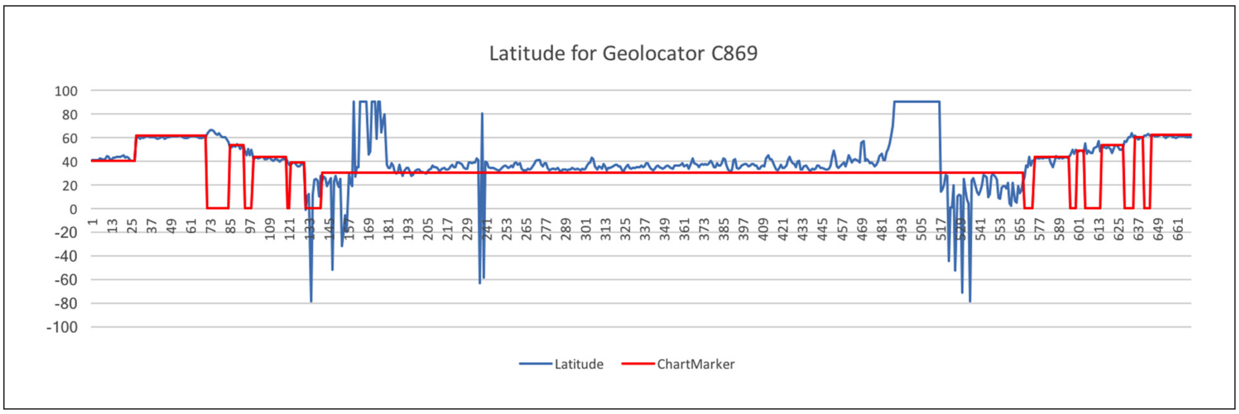


Latitude

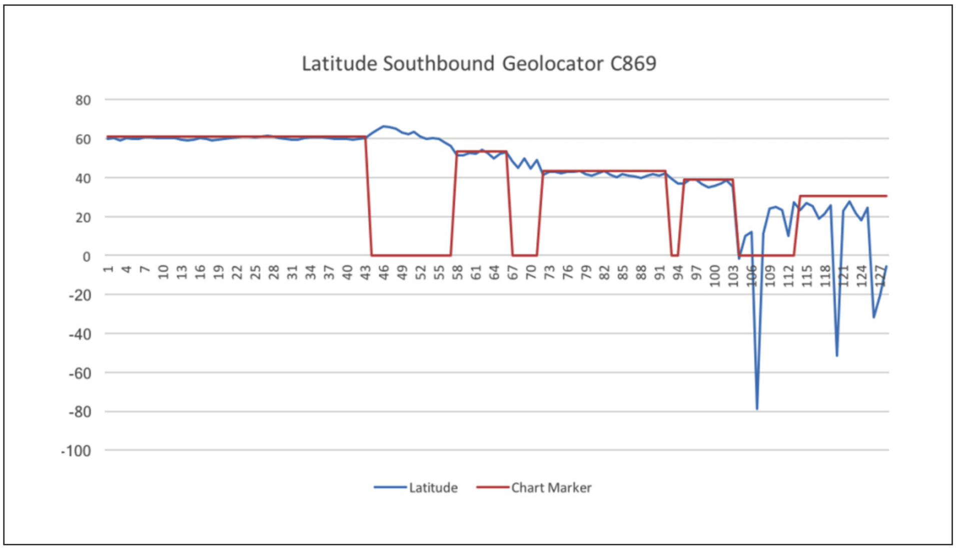
Latitude is heavily skewed by weather, and weather shading only dislocates the fixes in one direction. There are no balancing fixes in the direction of 'more light' past the level of a perfectly clear and bright day. Therefore, latitude is not normally distributed, and using means of the geolocator latitude output is not as precise as other methods, such as clear day calibration. For geolocators calibrated during clear days the true location is typically within 200 km of the estimated location, as measured in this paper at the Chukotka locations, and as found by other projects (Porter & Smith 2013, Tomkovich *et al.* 2013).

The red line in the chart below serves as a marker and indicates the latitudes of the most clear day on a given stationary period, which will be closest to the true position when the track has been set to a clear day during the calibration period (Porter & Smith 2013). If there was no clear day during the calibration period, then the true position is north of the red line during summer or south of the red line in winter (which is more likely during short stops). The red line is thus a boundary, northern or southern, of the possible locations (see Porter & Smith 2013 for a detailed explanation).

Below is a chart of latitude for the whole year, where stationary periods are represented by the flat sections of red line (the blue line is the geolocator output). The steep false spikes in the blue line occur near equinox (positions 133–181 around the 22 September equinox, and 481–565 around the 22 March equinox), or during shading distortions from bird activity, weather, or dirt on the sensor, etc. (e.g. between positions 229 and 241). As many as three weeks on each side of equinox may be useless for latitude estimations.



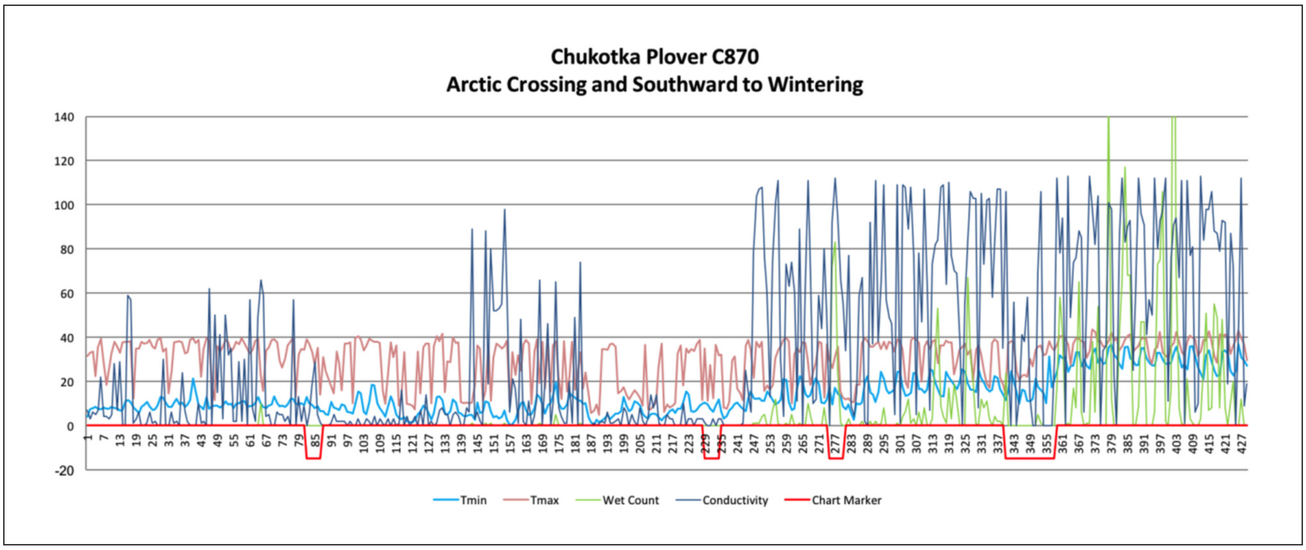
Below, the southbound section of the above chart is enlarged. Most latitude estimations fall on one side of the red line (which side reverses with equinox, 22 June and 22 September). The red line is either the true position, or else the true position is some distance away from the red line, on the side away from the blue line. This distance can be determined in many cases by a coastline ('coastal masking'), and as stated above, it is typically within 200 km for well-calibrated geolocators.



TEMPERATURE AND CONDUCTIVITY

For all periods of suspected flights (i.e. non stationary periods as defined by previous analysis of latitude and longitude – see above) both temperature and conductivity were examined visually. Geolocators were set in mode 3 (details from manufacturer: *www.migratetech.co.uk/IntigeoSummary.pdf*), where temperatures are sampled every five minutes with the maxima and minima recorded to memory every four hours. Conductivity is sampled every 30 seconds, and the maxima recorded every four hours. Wet count records how many times a conductivity above level 63 (brackish salt water) is encountered each hour.

In previous analyses (Porter & Smith 2013), non-stationary periods were accompanied by lower Tmin, lower Tmax (presumably due to altitude), and a drop to zero conductivity and wet count. However, this pattern is lacking during the Chukotka Plover migrations. The following plot shows maximum temperature (Tmax), minimum temperature (Tmin), salt water wet count (Wets), and conductivity (Cond) from Chukotka Plover No. C870, during the arctic crossing and southward migration. The horizontal axis is time (at four-hour intervals), the red line marks non-stationary periods when at –15. The overall pattern is remarkably different between the central arctic period (before position 241) and elsewhere (after position 241). Even in the absence of a large 'flight gap', a change of habits and/or habitat or location is distinctly visible.



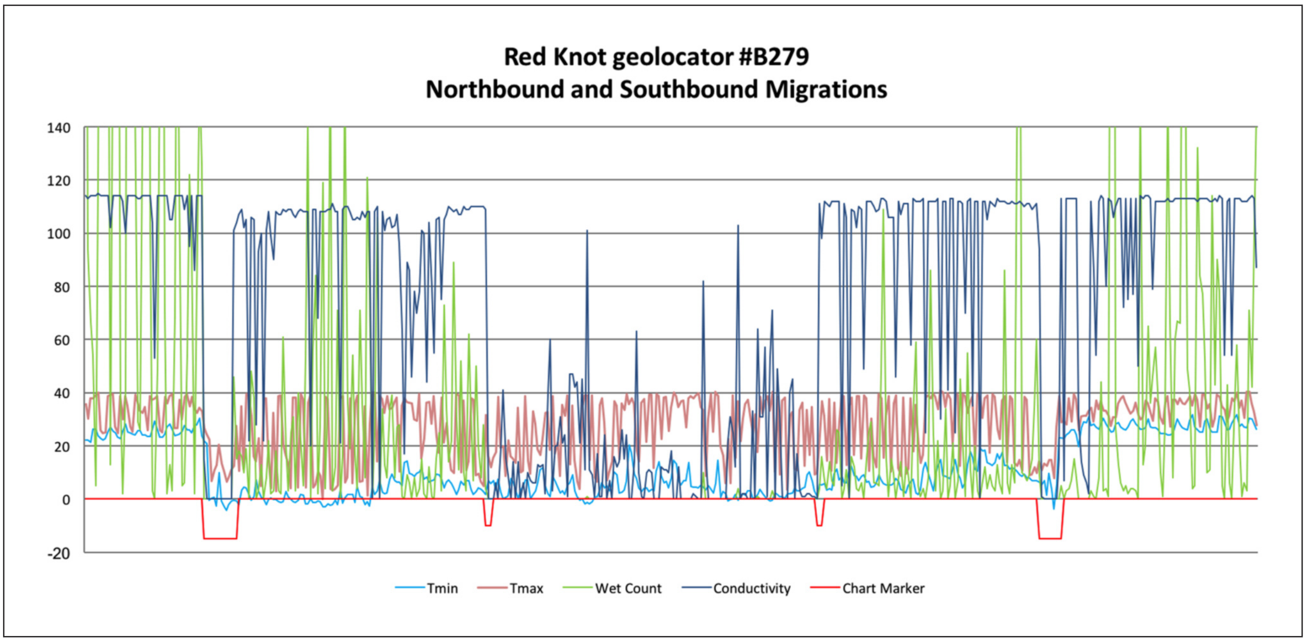
When a long flight is expected (marked by four negative periods in the red line) Tmin and Tmax do not drop dramatically, and Cond shows readings throughout those periods. Conductivity sometimes indicates a saline signal (level 60–120), other times freshwater, but seldom zero. Any consistent conductivity reading is associated with the bird being on the ground (although flying through rain will also produce a low freshwater signal), and combined with the occasional wet count, we interpret this to mean the bird stopped *en route* more frequently than every four hours.

Tmin is not affected by the bird's body temperature, so is closer to ambient than Tmax, and can be seen at the right end of the chart to be generally rising, as should be expected as the bird moves southward. Tmax is unclear, as the 40°C level is near body temperature.

Conductivity records salt water (Conductivity level 50–120) during part of the later third of the arctic passage, but fresh water before that. After leaving the arctic and turning south, fresh water is recorded until reaching the Kazakhstan region (where salt water bodies exist). 'Wet count' is triggered only in areas of salt water, where it can indicate how frequently the bird enters a salt water habitat. In other cases (Battley & Conklin 2017), it can be used to time the departure or arrivals of long flights, but does not appear useful for Chukotka Plovers.

Even though these parameters do not provide clear indication of flight periods for the Chukotka Plovers, they are interesting in their portrayal of changes in habits/habitats. Preference for salt water or fresh water often accompanies a change of location, as does a change in the level of Tmin. In contrast, Tmax is often just a measure of how often the bird raises its leg or sits and warms the sensor. However, with horizontal leg mounting, Tmax often is seen to drop during migratory flights of other species (RP unpubl. data). For the Chukotka Plovers, we interpret these parameters and patterns to mean there was least one stop every four hours (frequently more), and that migratory flight occurs near surface temperatures.

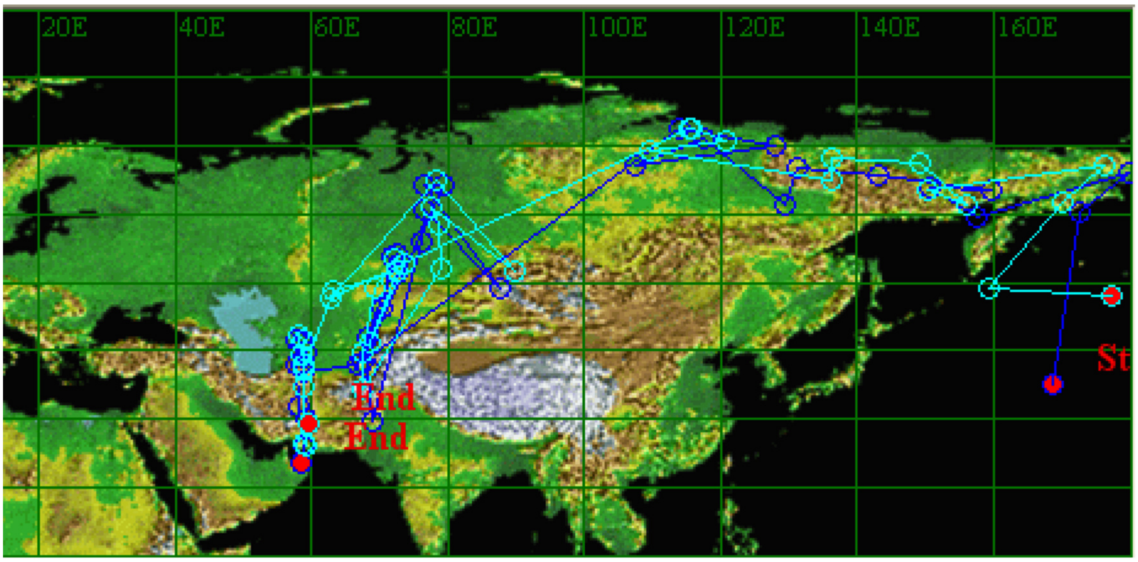
In contrast to the Chukotka Plovers, Red Knots often make long flights without stops *en route*. This contrast is good evidence of the different styles of migration. Below is the chart of maximum temperature (Tmax), minimum temperature (Tmin), salt water wet count, and conductivity from a Red Knot migrating from Texas to the arctic and back (courtesy of D. Newstead, Coastal Bend Bays & Estuaries Program, Inc., Corpus Christi, Texas, and L. Niles, Delaware Bay Shorebird Project, unpubl. data):



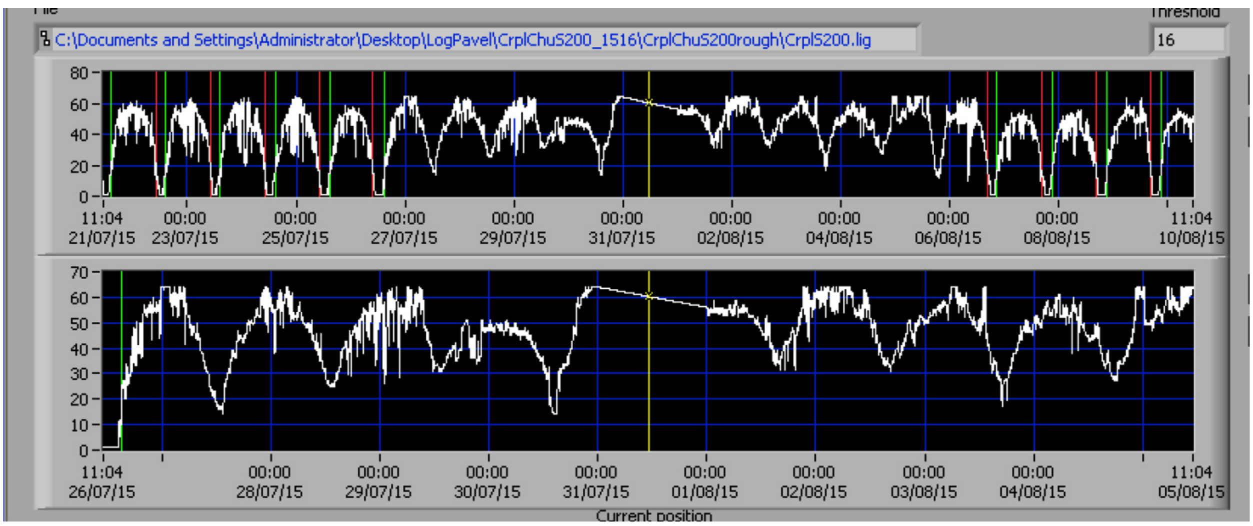
There were two long flights (red line values –15), both accompanied by lower Tmin, lower Tmax (presumably due to altitude), and drop to zero conductivity and wet count. This is the pattern lacking during the Chukotka Plover migrations. The two smaller red spikes (value –10) are also flight periods, but when passage was a short distance across the lower arctic, at surface temperatures and with fresh water stops. These are similar to the observed Chukotka Plover patterns.

ARCTIC LOCATIONS

The passage north of the Arctic Circle was investigated by increasing the light threshold to 40. This considerably increases the shading dislocations, but it can provide insight into stops *en route*, if any, and approximate longitudes where they occur. Below is the raw data in BAStrak BirdTracker for the arctic crossing of C869 using threshold 40. Fixes where the route reverses indicate slowing or stopping. There appear to be three or four 'hesitations' in the steady westward progress, but there are no long stopovers. The fixes have been dislocated south of the true position by shading, so the true position was north of the blue lines (light blue line connects mid-day fixes; dark blue line connects the midnight fixes). While the Arctic Ocean provides a northern border, the width of this band along northern Siberia ranged from 0–200 km in the east to 0–800 km in the west (where the coast juts northward).



The plot of the light signal also contains indications of movement northward towards the arctic (northernmost locations), then southward, as if the bird was following a great circle route westward. Below is the chart of light level vs time for the arctic passage of Chukotka Plover S200, in BAStrak Transedit2 (with the threshold of 16 as used in the reminder of the analysis). This is the most clear of the five geolocators, but all follow the same pattern (note that the lower section is the enlarged center section of the upper section).



At the center of the chart, from 31 Jul 2015 to 01 Aug 2015, the bird was at the northernmost latitude, in the zone of 24-hr daylight. Prior to 31 Jul 2015, night (zero light level) gradually increases as the bird passes northward, and gradually decreases again after 01 Aug 2015, when the bird is moving southward. As above, vertical lines in red (dusks) and green (dawns) are only plotted when fixes are possible at the given threshold.

Additional information on longitude may be obtained from the light signal above. The lowest level each day marks a 'transit', although it contains not just the solar shading, but also shadow of the bird, weather, and habitat. If the center of this 'transit' is marked, it can be processed in BAStrak to yield a rough longitude, much the same as raising the threshold. The 'transit' will also progress later as the bird moves westward, and if it does not, the bird is stationary. This procedure was deployed on the Chukotka Plovers in this study and these did not exhibit stops of more than one to two days during the arctic crossing.

REFERENCES

Battley, P.F. & J.R. Conklin. 2017. Geolocator wetness data accurately detect periods of migratory flight in two species of shorebird. *Wader Study* 124: 112–119.

Porter, R. & P.A. Smith. 2013. Techniques to improve the accuracy of location estimation using light-level geolocation to track shorebirds. *Wader Study Group Bulletin* 120: 147–158.

Tomkovich, P.S., R.R. Porter, E.Y. Loktionov & L.J. Niles. 2013. Pathways and staging areas of Red Knots *Calidris canutus rogersi* breeding in southern Chukotka, Far Eastern Russia. *Wader Study Group Bulletin* 123: 181–193.