Integrated Management and Visualization of Animal Telemetry Observations: Serving data from a wide variety of platforms used in animal telemetry

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***Abstract*- In the past two decades, rapid advances in animal transmitters, data storage tags and tracking technology have made it possible to use animals to collect high quality biological and oceanographic observations as they cruise through ocean habitats. However, despite significant investment in tagging and tracking technology, integrated data management and visualization systems have lacked. The growing volume of these data holdings, the large diversity of tag types and data formats, and the general lack of data management are not only complicating integration and synthesis of animal telemetry and tracking data but potentially threatening the integrity and longer-term access to these valuable datasets. To address this critical gap, the United States Integrated Ocean Observing System (U.S. IOOS) Animal Telemetry Data Management and Visualization System (ATN DAC) has been developed to provide an integrated system of most known transmitters and tracking systems. The ATN DAC in its first version provides a clean and intuitive Google Maps-based user interface with simple, color-coded icons for various tag types, including satellite-linked tags, archival tags, pop-up satellite archival tags, acoustic receiver buoys and autonomous mobile gliders equipped with acoustic receivers. For each tag type, the user can display additional data (e.g., animal track, acoustic detections) by simply clicking on the icons. An icon click also presents the user with a variety of additional options, which vary by platform. These include: display or download depth and temperature profile or conductivity data, display or download animal tracking data, display or download detection data, or view and query datasets through a webservice such as NOAA-Environmental Research Division's Data Access Protocol (ERDDAP) server. These data management and visualization tools are designed to enable Animal Telemetry data sharing and integrating biological data with environmental data observations and models. In this presentation we provide an overview of the ATN DAC data management and visualizations capabilities (figure 1) and linking this data service to ocean models and applications.**

I. INTRODUCTION

Technological advances in the last decades have made it possible to track animals with remote-sensing devices, i.e. "tags". Tracking devices yield detailed data regarding the physical environment through which the animals are moving. Sometimes this can be done in near-real time – true telemetry - and in other tags the data are stored for later acquisition. Animal species that have been tagged range from 20-gram salmon smolts to 150-ton whales [1], [2]. Detailed observations of animal movements and their aquatic environment have significantly improved our understanding of ecosystem function and the evolutionary constraints of species.

Rapid advances in animal transmitters and data storage tags have made it possible to use animals to collect high quality biological and oceanographic observations as they cruise through ocean habitats [3], [4], [5]. Block et al. 2012 [2] listed about 10 standard tag types exist with distinct position and sensor capabilities (see examples in Fig. 1). Sharks, tunas, salmon, sturgeon, marine mammals, reptiles and seabirds have been tagged routinely with sophisticated instruments that sample biological behaviors (diving), oceanographic variables (pressure, light, temperature, salinity), position (GPS, ARGOS, Geolocation) and biology/physiology (body temperature, heart rate, blood or tissue oxygen saturation, tail-beat, sound).

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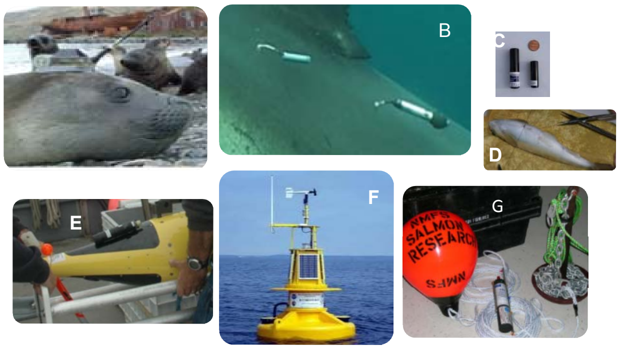

Figure1. Examples of tags used on marine animals. A. Sea Mammal Research Unit CTD tag on elephant seal (Source: Michael Fedak, Univ. of St. Andrews, UK).
B. Wildlife Computers PSAT, E. Lotek archival TDR on shark. (Source: Barbara Block, Stanford Univ., CA). C. Vemco acoustic tags, D. Salmon Smolt tagged with vemco tag, (Source: John Kocik, NOAA. Fisheries). E. Seaglider fitted with Vemco (Source: John Payne, UW/POST). F. Cabled acoustic receiver in CBIBS Buoy (Source: Doug Wilson, NOAA, NCBO). G. Vemco receiver VR2 used by NMFS Salmon Research group in Maine (Source: John Kocik, NOAA. Fisheries).

Some tags report profiles of the water column to satellites in near-real time. In cases where animals return to predictable haul-out sites, where exploitation rates are high (tunas), or where aggregation occurs around buoys (FADS), the tags are recovered and the entire archived time series can be downloaded. Together, these technologies provide the means to track animals for multiple years, providing seasonal, annual and climatological data.

In addition to tags that record environmental data, some sensors transmit acoustic data to underwater receivers. This results in a cable free underwater network for recording animal movements and is particularly useful for studying small animals, and aquatic species that do not surface often [6]. The decreasing size, longer life spans of batteries and increasing sophistication of acoustic transmitters [7] provide a mechanism for monitoring the behavior of a wide range of species across great distances, using networks of underwater receivers that span multi-national boundaries.

Complementing these networks is the emerging use of satellite enabled acoustic receivers and fixed or unmanned mobile gliders fitted with acoustic receivers (Fig. 1). This open new frontier for tracking marine living resources and create new and productive partnerships between physical oceanographers and biologists [2]. These collaborations have substantially increased the capacity to sample and understand the oceanography along our coastal waters as well as in remote locations. Animal telemetry provides unique datasets for resource management and ocean modelers [2].

However, despite significant investment in tagging and tracking technology, integrated data management and visualization systems have lacked. The growing volume of these data holdings, the large diversity of tag types and data formats, and the general lack of data management are not only complicating integration and synthesis of animal telemetry and tracking data but potentially threatening the integrity and longer-term access to these valuable datasets. To address this critical gap, the United States Integrated Ocean Observing System (U.S. IOOS) Animal Telemetry Data Management and Visualization System (ATN DAC) has been developed to provide an integrated system of most known transmitters and tracking systems. In this paper we provide an overview of the ATN DAC data management and visualizations capabilities and linking this data service to ocean models and applications.

II. ATN DATA ASSEMBLY CENTER

The ATN DAC system is built as a quasi-centralized system, with data fed into servers at NOAA Southwest Fisheries Science Center in Santa Cruz, CA and Stanford University. At Stanford, the data is processed from providers (Collection and Location by Satellite (CLS), Iridium, users returning archival tags), backed up at several locations [Hopkins Marine Station, Stanford University main campus, and NOAA Southwest Fisheries Science Center (SWFSC)], served to NOAA SWFSC, and then displayed as the ATN DAC user interface (http://oceanview.pfeg.noaa.gov/ATN/).
The DAC is designed to handle diverse types of archival, satellite, and acoustic telemetry data from an array of individual researchers and large programs. It is based on guidelines for user data and metadata, QA/QC, archiving data in standard formats, and distributing the data through common web services to support value added services for data submitters and users. The ATN data management systems both address the needs of the ATN and soon will subscribe to the IOOS Data Management and Communication (DMAC) guidelines of the IOOS.

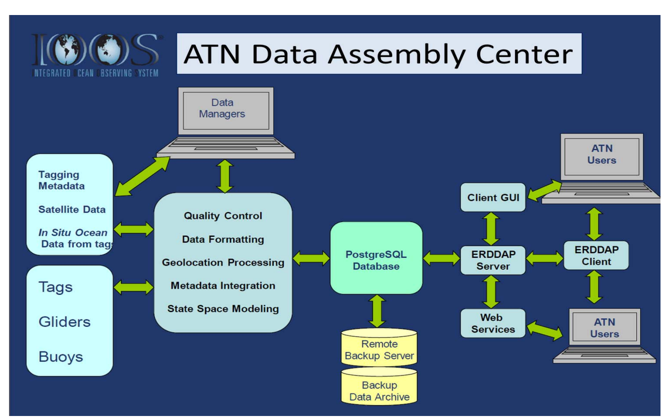

Figure 2. Overview of technical architecture of the ATN DAC.

The ATN DAC in its current version provides access to four data streams (Fig 2):

1. Live data from the animal-borne platforms reports automatically from Argos satellites via codes that directly download from the CLS to Stanford servers and then display location and data sets to the DAC in near-real time.
2. Acoustic data is collected directly from archival receivers and via automated Iridium satellite linked acoustic receivers mounted on stationary buoys or mobile platforms such as Wave Gliders.
3. Pop-up satellite tags collect data while they are attached to an animal and are pre-programmed to release and float to the surface after a specified period of time. Once they reach the surface, the data takes up to 20 days to download and transmit to the DAC. The DAC servers collect position as well as oceanographic and behavioral data, which is both rapidly displayed and archived on the tag.
4. Archival based data are drawn from the thousands of animal tracking deployments and datasets collected by various tagging programs using implantable archival tags and pop□up archival tags that have been recovered.

III. ATN DAC WEB VISUALIZATION INTERFACE

The DAC web display and interface was made possible by leveraging prior developments for tag data management (e.g., Global TOPP into a single system with an intuitive front end, capable of delivering and visualizing U.S. telemetry data streamed from multiple animal and platform types. Currently, the ATN DAC provides graphical displays or downloads of ocean profile data, location data for track visualization in real-time, and acoustic detection data (Fig. 3).

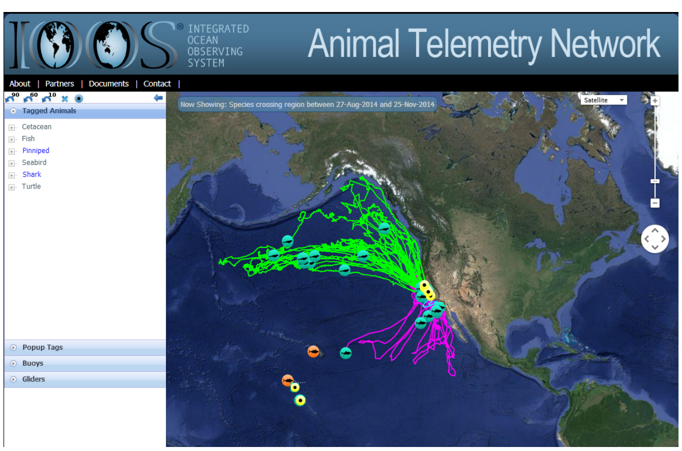

Figure 3. ATN DAC web portal graphical display that includes location data for track visualization in real-time.

All these data can be downloaded via IOOS standard service (e.g., ERDDAP), and are accessible at http://oceanview.pfeg.noaa.gov/ATN/ (Fig. 4).

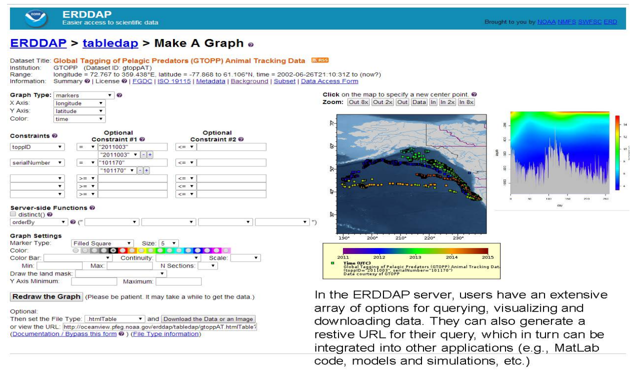

Figure 4. All data can be downloaded via IOOS standard service (e.g., ERDDAP). This website is accessible at http://oceanview.pfeg.noaa.gov/ATN/.

The DAC graphical display uses a Google Maps based user interface that was created with simple, color coded icons representing five distinct tag platform types: real time satellite tags with oceanographic data; satellite tags with position-only(Fig. 5)., pop-up satellite archival tags; archival tags; acoustic tags; and autonomous buoys with receivers for acoustic detection (Fig. 6). For each platform type, the user can display additional data types (e.g., animal or glider track, acoustic detections) and metadata (platform type, date and duration of deployment) by simply clicking on the icon

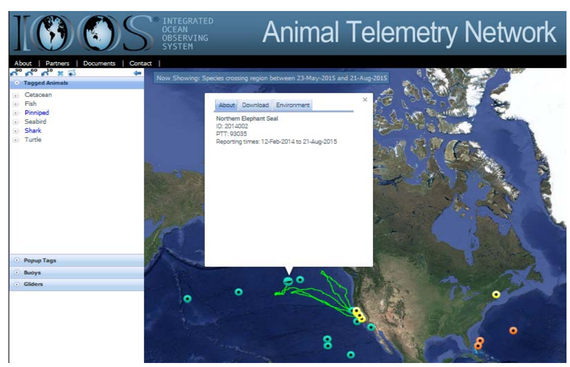

Figure. 5. By clicking on the icon, for example northern elephant seal in this case, the user can display additional data types and metadata (platform type, date and duration of deployment) .

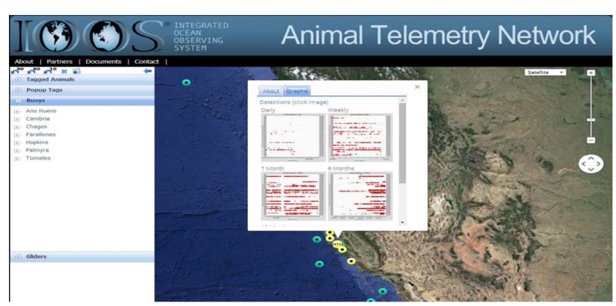

Figure. 6. Show daily, weekly, monthly and 6 months acoustic tag detections.

An icon click also presents the user with a variety of additional options that vary by tag platform.
The default view of the IOOS DAC interface shows the most recent data (users can select from 10, 60, or 90 day displays), and the interface features a pull out Data Menu which allows users to view or hide datasets from each species and platform by clicking check boxes arranged in a hierarchical, nested structure---similar to that used in Google Earth to activate and deactivate various data layers. At the individual tag level, users can also view, download, or access the data through an ERDDAP server, all directly from the Data Menu (i.e., without having to locate that specific tag on the map first). The ERDDAP server enables users to quickly query, visualize, and download data in 37 formats, including CSV, NetCDF, MatLab, KML, Shape, etc.) (Fig. 4). More importantly, once the user has created a query, ERDDAP provides a restive URL for that query that can be incorporated directly into other systems (e.g., websites, Matlab routines, and models) that require ongoing access to those data streams.

The DAC also provide options to overlay remote sensing data (SST and Chl. a) on top of animal tracks (Fig. 7).

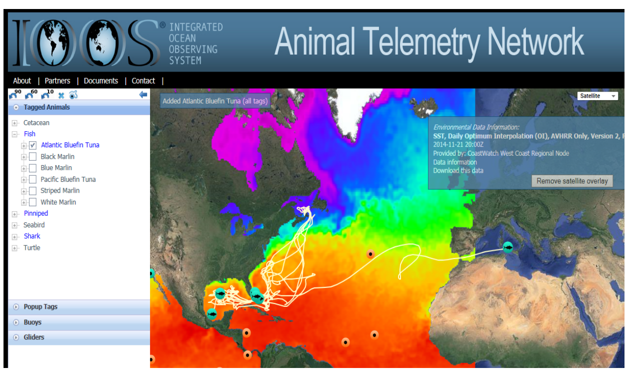

Figure. 7. Show overlay of SST data from remote sensing (SST, Daily Optimum Interpolation (OI), AMSR+AVHRR, Version 2)

III. CONCLUSIONS

The core of the ATN data management system is a quasi-centralized national ATN Data Assembly Center (DAC) designed to receive and distribute data and data products to partner organizations using IOOS Data Management and Communications (IOOS DMAC) data standards and services. The ATN DAC in its current version have the capability to enable Animal Telemetry data sharing and integrating biological data with environmental data observations and models.

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