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# GPS-INS-Pseudolite Integration and its testing using GPS Constellation Simulator

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## Abstract

Integrated Global Positioning System – Inertial Navigation System (GPS-INS) techniques have been used in a variety of kinematic applications for many years. In such integrated systems, high accuracy GPS measurements are used to estimate and to the time-dependant systematic error states of the INS. High data rate INS measurements can then provide accurate position and attitude information between the GPS updates. It must be emphasized that satisfactory results cannot generally be provided in the free navigation mode during periods of GPS signal outage because the INS accuracy deteriorates rapidly with time. Moreover, if the blockage in GPS signals continues longer than the acceptable INS bridging level, it would be very difficult to recover correct GPS ambiguities due to the significantly increased INS position errors. Pseudolites are ground-based GPS signal transmitters that can improve the “open air” signal availability or even replace the GPS satellites constellation for some indoor applications. They typically transmit signals at the GPS frequency L1 & L2. Both pseudo-range and carrier-phase measurements can be made on the Pseudolite signals. With the development of Pseudolite techniques and GPS user equipment during the past decade, Pseudolites have been proposed as a solution for enhancing the availability, reliability, integrity, and accuracy for many navigational applications.

The GPS research team at IIT Bombay, under the guidance of Prof. M N Kulkarni, as P.I. (Principal Investigator) is currently undertaking a research project on the development of a working model for the GPS-INS-Pseudolite integrated system with the help of GPS Constellation Simulator as an important aid during modeling, design and testing phase of the integrated system.

This paper describes the integration of GPS-INS-Pseudolite in general highlighting the utility of GPS Constellation Simulator as an effective testing tool in the integration. Besides it also describes an overview of the research project carried out in IIT Bombay.

**Keywords:** *GPS, INS, Pseudolite, Simulator, Integration, Modeling.*

## Introduction

Inertial Navigation Systems (INS) are being extensively used for position and attitude determination for a wide range of moving platforms such as spacecraft, airplanes, robotics, land vehicles, and vessels. INS consist of navigation computers, to calculate gravitational acceleration and to integrate the net acceleration, and an inertial measurement unit comprising of gyroscopes and accelerometers. However, when operated in stand-alone mode, there is a time-dependant growth of systematic errors (Wang et al., 2001). The satellite-based kinematic positioning techniques like Global Positioning System (GPS) offer consistent accuracy during the period of measurement. Besides, precise satellite measurements are ideally suited for the

calibration of INS systematic errors thus providing high-rate precise positioning and attitude information.

But GPS signals are relatively weak and can be easily obstructed thus decreasing the performance efficiency of GPS-INS integrated system. In case of underground or indoor operations, the GPS signals may be completely lost. To address this problem, the GPS-INS system can be augmented with a new class of ranging signals from ground-based transmitters called as pseudolites can be effectively used. Pseudolites are an innovative, complementary technology that offers opportunities to address a range of positioning and navigation applications that require robust performance (Lemaster, 2003). It can be expected that the augmentation of GPS/INS

systems with pseudolites will improve the performance of the whole system because the availability and geometry of precise measurements can be significantly strengthened.

The GPS research team at IIT Bombay, under the guidance of Prof. M N Kulkarni, as P.I. (Principal Investigator) is currently undertaking a research project on the development of a working model for the GPS-INS-Pseudolite integrated system with the help of GPS Constellation Simulator as an important aid during modeling, design and testing phase of the integrated system.

The main objective of this paper is to present the basic information regarding the integration of GPS-INS-Pseudolite in general highlighting the utility of GPS Constellation Simulator in the integration.

### GPS-INS integrated system

According to Newton's second law of motion, inertia is the propensity of bodies to maintain constant translational and rotational velocity, unless disturbed by forces or torques, respectively. An inertial reference frame is a coordinate frame in which Newton's laws of motion are valid (Grewal et al., 2001). 'Inertial Navigation System' (INS) provides the position, velocity, orientation, and angular velocity of a vehicle by measuring the linear and angular accelerations applied to the system in an inertial reference frame. Also called as inertial guidance system, INS consists of an Inertial Measurement Unit (IMU), combined with a set of guidance algorithms and control mechanisms, allowing the path of a vehicle to be controlled according to the position determined by the inertial navigation system. An Inertial Measurement Unit is a closed system that is used to detect altitude, location, and motion. Typically, an IMU detects the current acceleration and rate of change in attitude i.e. pitch, roll and yaw rates, as described in figure 1, and then sums them to find the total change from the initial position.

INS, however, require initialization, which is the process of determining initial values for system position, velocity, and attitude in navigation coordinates. INS position initialization ordinarily relies on external sources such as GPS or manual entry. INS alignment is the process of aligning the stable platform axes parallel to navigation coordinates for gimballed systems or that of

determining the initial values of the coordinate transformation from sensor coordinates to navigation coordinates for strapdown systems (Grewal et al., 2001). A typical inertial navigation system integrates the information gathered from a combination of gyroscopes and accelerometers in order to determine the current state of the system. Gyroscopes measure the angular velocity of the system in the inertial reference frame while. Accelerometers measure the linear acceleration of the system in the inertial reference frame, but in directions that can only be measured relative to the moving system, since the accelerometers are fixed to the system and rotate with the system, but are not aware of their own orientation



Fig.1 - Description of pitch, roll and yaw in INS (en.wikipedia.com)

But INS suffer from integration drift. Small errors in the measurement of acceleration and angular velocity are integrated into progressively larger errors in velocity, which is compounded into errors in position. This is a problem that is inherent in every open loop control system. The inaccuracy of a good-quality navigational system is normally less than 0.6 nautical miles per hour in position and on the order of tenths of a degree per hour orientation. One of the most common alternative sensors is a satellite navigation radio such as GPS. By properly combining the information from an INS and the GPS system, the errors in position and velocity can be made stable (Wang et al, 2001).

The GPS, officially also known as NAVSTAR (Navigation and Satellite Timing and Ranging), is part of a satellite-based navigation system developed by the U.S. Department of Defense. GPS belongs to a large class of radio navigation systems that allow the user to determine his range and/or direction from

a known signal transmitting station by measuring the differential time of travel of the signal (Grewal et al., 2001). The GPS is the only fully functional satellite navigation system developed by the U.S. Department of Defense (DOD) in the early 1970s. A constellation 24 GPS satellites broadcasts precise timing signals by radio, allowing any GPS receiver (abbreviated to GPSr) to accurately determine its location (longitude, latitude, and altitude) in any weather, day or night, anywhere on Earth. Only four satellites are needed to provide the position or location information. GPS satellite orbits are nearly circular with an inclination of about  $55^\circ$  to the equator. Satellite altitude is of about 20,200 km above the Earth surface. The number of satellites in the GPS constellation has always been more than 24 operational satellites. GPS has become an effective tool in monitoring post quake information, crustal deformation, atmospheric monitoring, and civil aviation purposes so and so forth.

The performance of an integrated INS/DGPS is a complex process depending on (Skaloud, 1999):

- Quality and type of inertial sensors
- Baseline length
- Operational aspects
- Validity of error models
- Estimation algorithm.

Another limiting factor is band frequency. In the lower frequencies, the INS/DGPS integration reduces the overall error; and in the high frequencies, the overall error is not reduced. The existing integrated GPS/INS systems may suffer poor performance under harsh observing conditions. In the case of GPS, sufficient number of 'visible' satellites cannot be guaranteed everywhere. Even when some low elevation satellites can be tracked, the measurements from these satellites are contaminated by rather high atmospheric noise. Therefore, this significant drawback of existing systems results in the poor accuracy in the vertical coordinates, which is about three times worse than that of the horizontal coordinates. This will also pertain to the poor accuracy of the pitch angles - one of the attitude parameters in an attitude determination system. This problem can be adequately addressed by the inclusion of additional pseudolite measurements with low elevation angles (Wang et al., 2000).

## Pseudolites

Pseudolite is a contraction of the term "pseudo-satellite," used to refer to something that is not a satellite but performs a function commonly in the domain of satellites. Pseudolites are most often small transceivers that are used to create a local, ground-based GPS alternative. This is also known as a Local Area Augmentation System (LAAS). The range of each transceiver's signal is dependent on the power available to the unit. Being able to deploy one's own positioning system, independent of the GPS, can be useful in situations where the normal GPS signals are either blocked/jammed such as military conflicts, or simply not available such as exploration of other planets (LeMaster et al., 2003). Figures 2 & 3 show a typical pseudolite transmitter.

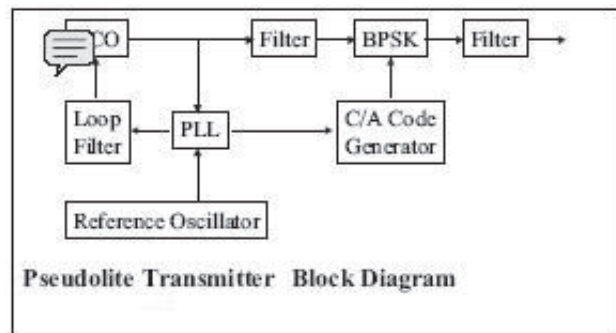


Fig.2- Pseudolite Transmitter Block Diagram (Stone et al, 1999)

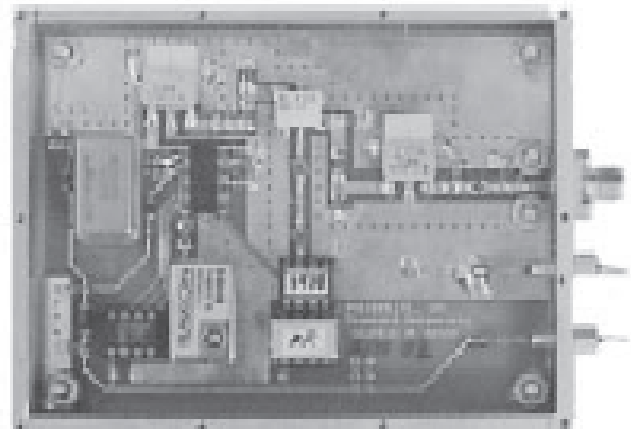


Fig. 3 -Typical Single Frequency Pseudolite (Stone et al, 1999)

Typically ground-based, they can aid in GPS positioning in three main ways. First, they can be used to augment the GPS satellite constellation by providing additional ranging sources when the natural satellite coverage is inadequate. Applications for which this additional coverage is beneficial include

navigation in places with limited sky visibility, such as urban canyons and open pit mines, as well as some on-orbit applications involving relative positioning of spacecraft. Second, pseudolites can be used as an aid to carrier-cycle ambiguity resolution when using carrier-phase differential GPS (CDGPS) for precise positioning. Motion-based integer resolution using only satellites is often a slow process because of the slow rate of change in the line-of-sight vectors to the satellites. In contrast, a receiver in the presence of a local pseudolite can see a large change in the line-of-sight vector with relatively little absolute motion on the part of the receiver. This can yield integer resolution in a matter of seconds. Third, pseudolites can be used to replace the GPS constellation completely. This is generally done to emulate GPS positioning indoors, although more exotic locales—such as underground or on the surface of other planets—have also been proposed. Most of these final classes of applications use CDGPS rather than code-phase positioning because of the relatively small working volume of the pseudolite array.

### Mathematical Models for INS, GPS, and Pseudolite Integration

In an integrated GPS/INS/Pseudolite, or INS/Pseudolite, system the time-dependent systematic errors in INS systems are calibrated using precise GPS/pseudolite positioning solutions in a loosely coupled mode, or using precise measurements in a tightly coupled mode. Both these integration modes have advantages and disadvantages. Some tests have shown little difference in the accuracy of the results (Wei & Schwarz, 1990). No matter which mode is chosen for the integration algorithm, a Kalman filter is commonly used as the data fusion tool.

The basic mathematical models for a Kalman filter include the dynamic model and measurement model:

#### Dynamic Model

The dynamic model for a physical process can be constructed in the vector matrix form as a set of first order differential equations:

$$\dot{x}(t) = F(t)x(t) + w(t)$$

where,

$x(t)$  is the state vector;

$F(t)$  is the dynamic matrix;

$w(t)$  is the noise vector.

The basic states in the dynamic model include nine navigation parameters, three accelerometer bias parameters and three gyro drift parameters. The coefficient blocks in the dynamic matrix  $F(t)$  for the navigation and major INS error states can be formed using a terrestrial INS psi-angle error model:

$$d\gamma = -\rho d\gamma + dv$$

$$dv = -(\Omega + \omega)dv + \nabla - \psi f + dg$$

$$d\psi = -\omega\psi + \varepsilon$$

where,  $d\gamma$  = the position error vector;

$dv$  = the velocity error vector;

$d\psi$  = the attitude error vector;

$\rho$  = the vector of rate of turn of the true frame with respect to the Earth;

$\Omega$  = the Earth rate vector;

$\omega$  = the angular rate vector of the true coordinate system wrt an inertial frame;

$\nabla$  = the accelerometer error vector;

$f$  = the specific force vector;

$dg$  = the error in the computed gravity vector; and

$\varepsilon$  = the gyro drift-rate vector.

Because both GPS/pseudolites and INS measurements are collected at discrete points in time,  $t_k$  ( $k = 1, 2, \dots$ ), for computational convenience, the dynamic equation is commonly converted into the discrete form.

$$x_k = \Phi_{k,k-1} x_{k-1} + w_k$$

where,  $\Phi_{k,k-1}$  is the transition matrix; and

$w_k$  is the noise vector.

#### Measurement Model

Generally, the measurement model can be expressed as:

$$z_k = H_k x_k + t_k$$

where,  $z_k$  is the measurement vector;

$H_k$  is the design matrix; and

$t_k$  is the noise vector.

In the case of tightly coupled integration, the

state vector may be augmented to include GPS/pseudolite carrier phase ambiguities and other parameters of interest (Grejner-Brezinska et al., 1998). While the GPS/pseudolite measurements can be used to calibrate INS systematic errors, the efficiency of such calibration will be very dependent on both the accuracy and intrinsic geometry of the GPS and/or pseudolite measurements used.

### Augmentation of GPS/INS with Pseudolite

The pseudolite ranging signals can contribute to a GPS/INS system by enhancing the geometric strength, improving the availability of the precise measurements for use in calibrating INS errors, and increasing the accuracy of the height component and some height-related states in the filter (Wang et al., 2000). The optimal locations of pseudolites should be identified so as to maximize the contributions of these additional signals. A geometric analysis can be carried out with appropriate optimization criteria, such as Position Dilution of Precision (PDOP) and Relative Position Dilution of Precision (RDOP).

### GPS Constellation Simulator

A simulation is an imitation of some real thing, state of affairs, or process. The act of simulating something generally entails representing certain key characteristics or behaviors of a selected physical or abstract system. The GPS constellation simulator simulates GPS-like signals. Traditionally the simulator consists of two functional components: the hardware and integrated firmware that generates the satellite radio-frequency signals, and a powerful computer workstation that runs the software environment and provides system control of the hardware. Modern simulators however incorporate the signal generation hardware into expansion card mounted on the computer itself thus reducing the bulk size. Thus the GPS constellation simulator aids as an efficient tool during the modeling, design and testing of a GPS-INS-Pseudolite integrated system.

The GPS research team at IIT Bombay, is currently undertaking a research project on the development of a working model for the GPS-INS-Pseudolite integrated system, under the guidance of Prof. M N Kulkarni, as P.I. (Principal Investigator). This project will be the first step in the simulation and development of a navigation system based on GPS-INS-Pseudolite integration. The second phase will involve the development of a navigation receiver while in the third phase, simulation and development

of the entire system will be achieved.

### Summary and conclusions

The time-dependant growth of systematic errors in inertial navigation systems can be calibrated using precise measurements from the satellite-based navigation systems. However, blockages and obstructions in the GPS signals can deteriorate the efficient operation of the GPS-INS navigation system. Pseudolites are ground-based transmitters that can be easily installed in required positions thus providing greater flexibility to the GPS-INS navigation systems for a variety of indoor as well as outdoor applications. GPS Constellation simulators generate GPS-like signals and hence prove greatly useful during the modeling, design and testing phase of an integrated GPS-INS-Pseudolite navigation system. The IIT Bombay GPS research team is currently undertaking a research project on the development of a working model for GPS-INS-Pseudolite based navigation system.

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# Wild Life Ecology (Remote Sensing & Geo Informatics)

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## Abstract

Remote sensing is the science and art of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation.

Remote sensing which provides spatial data is a less used but is powerful tool to get precise and upto date information essential for wildlife management. Though technically complex, the remote sensing methods have revolutionalised the process of map making and for data gathering. Remote sensing can be applied to wildlife habited inventory, evaluation and wild life census . Wildlife habitant mapping is similar to any type of land cover mapping.

**Key Words:** Ecology, Censuing, perpetuating, ecosystems, constellation

## Introduction

A natural environment is self-renewing, self-perpetuating and stable one in which every organism contributes in some way, howsoever small to the overall stability. In natural ecosystems, the plants and animals have evolved at their own pace and in their own way under the influence of natural selection to fit in the constellation of certain environment factors. In the process, they help to sustain, each species controlling its own population growth and at the same time limiting of other species, so that a reasonable ecological balance may be achieved and maintained for hundreds of years. The term wild life applies to all biological elements that comprise every species of plant and animal in the world excluding man and his undomesticated pet. Wildlife all over the worls is vanishing rapidly presently due to growing influence of humans. The pressure of modernisation, along with uncontrolled growth of the human population and commercial exploitation have been the prime causes for the decline of wild life in almost all the countries. Man has ruthlessly destroyed nature in search of food, water and shelter. As a result the formerly secure wildlife habitat have been depleted and fragmented. In reality, it is extremely necessary to have a peaceful co-existence with nature and natural life for the development and progress of human beings.

## Application of Remote Sensing

### *Estimation of Tigers*

Tigers (Panthera tigris) were once widely

distributed across the riverline grass lands and forests of Asia. As human populations converted the rich plains to agricultural lands, Tigers gradually became confined to the forest of the region. There were, however, still an estimated 40,000 tigers on the Indian subcontinent in the early 1900s. After World War II Clearing of forest lands accelarated forest loss and fragmentation. As a result tiger population now occur in small, isolated forest sanctuaries. Present tiger distribution extends from a population near the pacific coast of Russia to southern India, Malaysia and Sumatra. In India there have been four national tiger censuses since 1972 but none has provided information about population. Many Scientists believe that extinction of smaller tiger population is likely because

- 1) Populations are small and isolated.
- 2) The new threat of poaching is widespread and significant.

Remote sensing; Geographic information systems and rapid assessment techniques to determine the presence of tigers and the abundance of tiger prey are critical tools for analysis and planning at landscape and population level scales. These technologies provide a means of —

1. Mapping the distribution of tigers at a resolution needed to determine the extent of individual tiger population.
2. Monitoring these population to evaluate the success of conservation efforts.



Ground survey methods such as counting animals, trapping, will always be useful. However, in a number of cases other ground method survey have limitations as whole area cannot be accessed in one and information collected may not be as accurate as possible through remote sensing aided by limited ground survey.

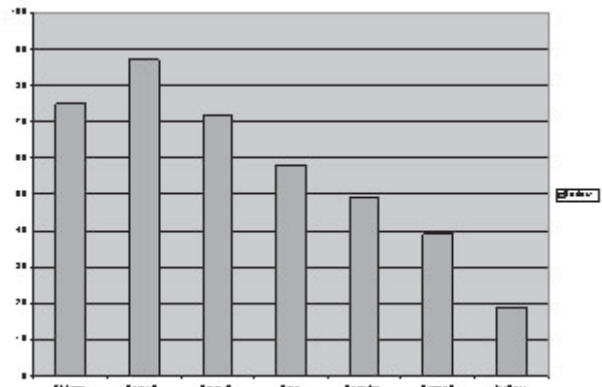
Tiger reserves in India

Name	State	Area
Bandipur	Karnataka	866
Corbett	Uttaranchal	1316
Kanha	Madhya Pradesh	1945
Manas	Assam	2840
Melghat	Maharashtra	1597
Palamau	Bihar	1026
Ranthambhore	Rajasthan	1334
Simlipal	Orissa	2750
Sundarbans	West Bengal	2585
Periyar	Kerala	777
Sariska	Rajasthan	866
Buxa	West bengal	759
Indiravati	Madhya Pradesh	2799
Nagarjunasagar	Andhra Pradesh	3568
Namdapha	Arunachal Pradesh	1985
Dudhwa	Uttar Pradesh	811
Kalakad Mundanthurai	Tamil Nadu	800
Valmiki	Bihar	840
Pench	Madhya Pradesh	758
Dampa	Mizoram	500
Panna	Madhya Pradesh	542
Bandhavgarh	Madhya Pradesh	1162
Taroba	Maharashtra	620
<b>Total</b>		<b>33,046.00</b>

Population Estimated of breeding tigers based on density estimates and area of distribution

Population	Total Area	Area in Reserves	Estimated Breeding Tigers	Estimated Breeding in Reserves	Estimated Total Population
Chitwan	2543	1921	69	50	196
Bardia	1840	938	50	25	143
Sukla Phonta	320	320	16	16	46
Dudwo	674	674	18	18	53

In central Nepal the Chitwan, Bardia and Dudwa population are estimated to have a density of one tiger per 37 Km<sup>2</sup>.



The ratio of good to poor tiger habitat across seven forest units in Central Nepal (Parsa R, Parsa reserve, Parsa-B, Parsa Buffer, Badr/Ind, Bhadmi).

- ❖ In India scientist have used remote sensing to evaluate the habitats for one horned Indian Rhino, Rahinoceros, Unicorn Sambar in Kaziranga, Kanha and Rajaji National Parks respectively.
- ❖ Aerial photography has been used successfully to detect prairie dog. Basking Gharials on river banks, Elephants in deciduous forest such as Madumalai or Rhinos in Kaziranga could be seen from air easily.

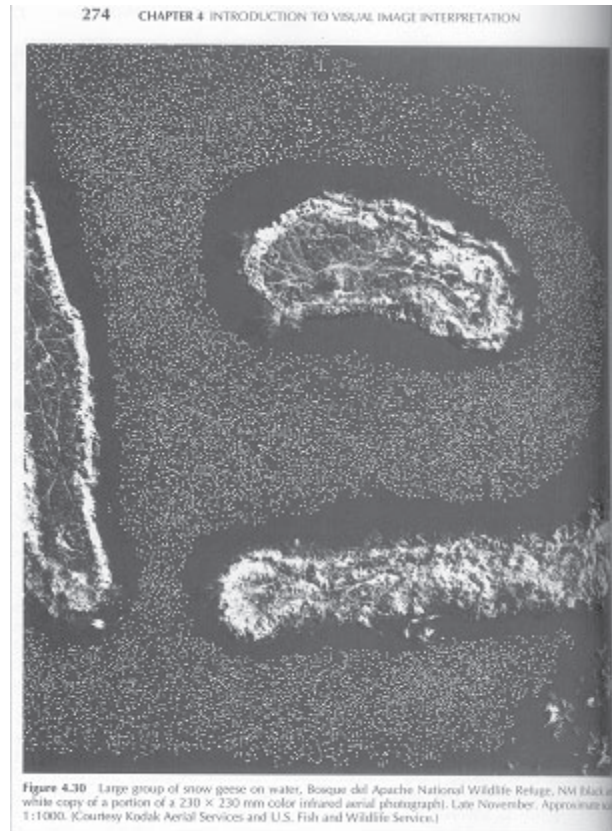
In India total of 85 National parks and 448 sanctuaries covering 4.5% of the total geographical area of the country .

- ❖ A variety of mammals and birds have been successfully censused using vertical aerial photography including Moose, Elephants, Whales, Elk, Sheep, deer, antelope, sea lions, beavers, seals, geese, ducks, flamingo, Oystercatchers and Penguins.
- ❖ Wildlife censusing also requires that individual animals be large enough to be resolved on the photographs. A scale not smaller than 1:8000 is

Station/Union Territory	Sanctuaries		National Parks	
	Total	Area (km <sup>2</sup> )	Total	Area (km <sup>2</sup> )
A & N Islant	94	455.56	8	1153.34
Andhra Pradesh	21	11832.54	4	372.23
Arunachal Pradesh	9	6177.45	2	2468.23
Assam	8	990.58	2	930.00
Bihar	19	3881.75	2	567.32
Goa	4	355.78	1	107.00
Gujarat	21	16970.16	4	479.67
Haryana	10	342.65	1	1.43
Himachal Pradesh	30	4702.87	2	1295.00
Jammu & Kashmir	15	10157.67	4	3900.07
Karnataka	20	4238.21	5	2471.98
Kerala	12	2143.36	3	536.52
Madhya Pradesh	32	10567.05	11	6485.72
Maharashtra	25	13995.49	5	958.45
Manipur	1	184.85	2	81.00
Meghalaya	3	34.21	2	267.48
Mizoram	3	560.00	2	250.00
Nagaland	3	24.41	1	202.02
Orissa	18	6214.96	2	1212.70
Punjab	6	294.82	0	-
Rajasthan	22	5662.87	4	3856.53
Sikkim	4	92.10	1	850.00
Tamil nadu	17	2671.03	5	401.63
Tripura	4	603.62	0	-
Uttar Pradesh	29	8107.52	7	5429.83
West Bengal	15	1055.55	5	1692.65
Daman & diu	1	2.18	-	-
Delhi	1	13.20	-	-
Chandigarh	1	25.42	-	-
Dadra & Nagar Haveli	-	-	-	-
Lakshadweep	-	-	-	-

recommended for large mammals such as Elk, whereas scales as large 1:3000 should be used for smaller mammals such as sheep, deer and antelope.

- ❖ Flocks of snow geese can be identified at a scale of 1:12000 against a dark background. Individuals birds are identifiable at scales of 1:6000 and larger.



- ❖ Large group of Whales, Northern Canada (Black and white copy of photograph taken with Kodak water penetration color film)