A John Deere Company

*The **leading pioneer** in GPS technology*

Precision Navigation in Agriculture

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NavCom Technology, Inc.

Presented at the Space Weather Workshop
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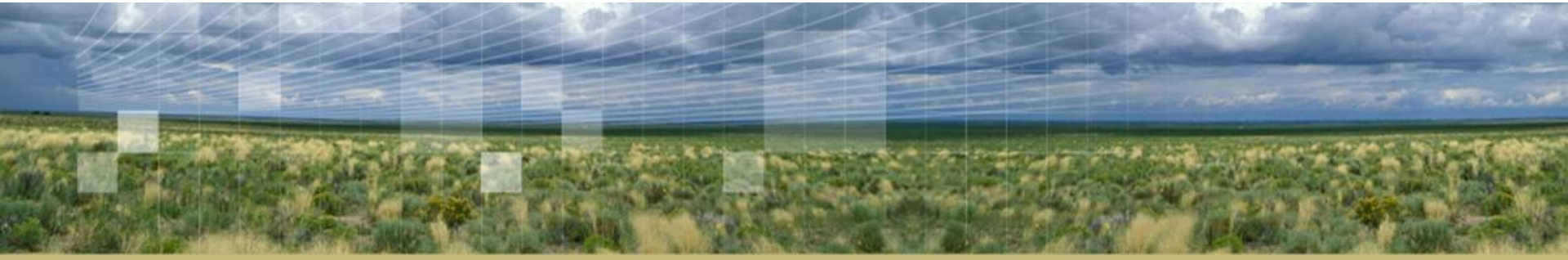


Presentation Outline

- Introduction – History
- Unique Technology
  - StarFire Global SBAS
  - RTK Extend
- Farming Applications
- Other Applications

80/80/80

First 80 Years

1837 John Deere Makes Self Scouring Plow

Second 80 Years

1918 John Deere Buys Waterloo Boy Tractor

Next 80 ? ….

1999 John Deere acquires NavCom

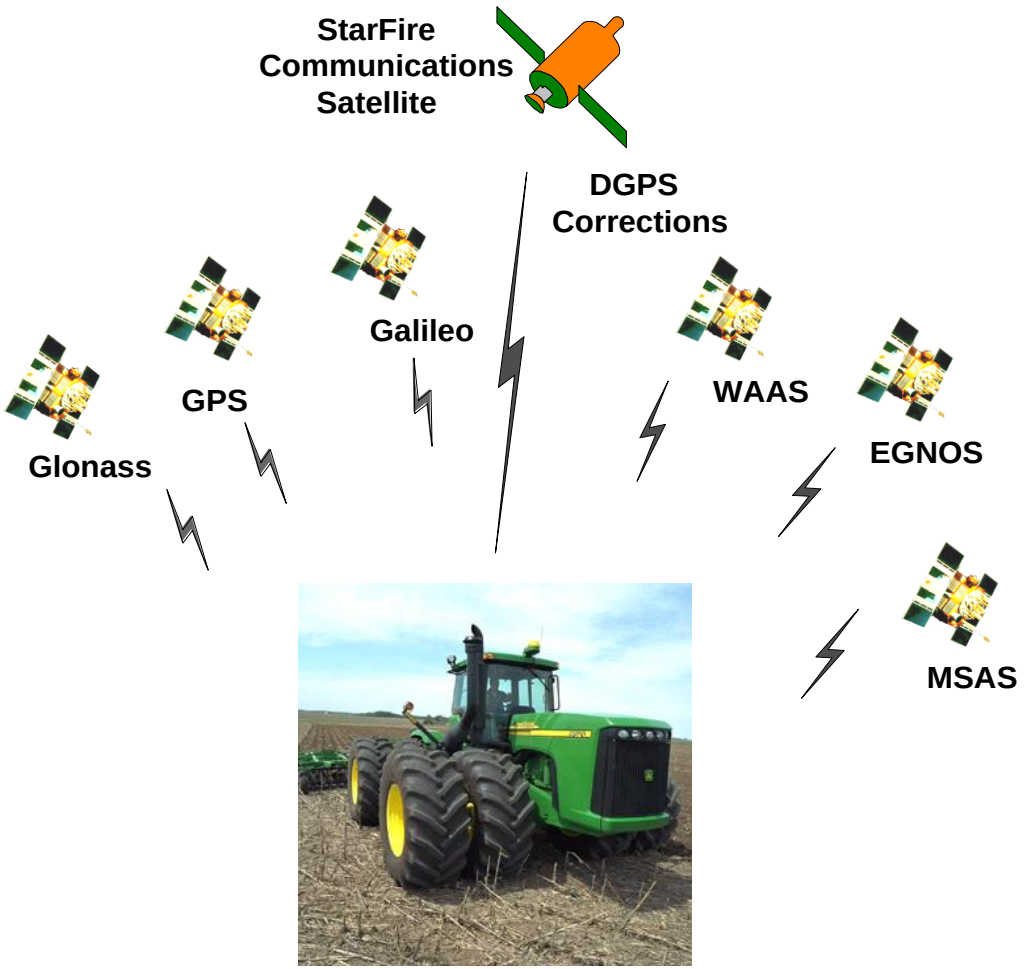
The farm is being transformed by precision navigation

NavCom Technology, Inc.

- Acquired by Deere & Co. November 1999
- Part of Deere's Intelligent Systems Group
  - Develops GNSS receivers and software for Deere and others
  - Development and maintenance of the StarFire Satellite Based Augmentation System
- Provider of precise positioning & navigation products and solutions external to Deere
  - Contract Engineering
  - Proprietary Products for precise positioning
  - Product Services (Global Differential GNSS Corrections)

Deere's use of GPS

- Deere needed a way to accurately position agricultural equipment on a global basis
- First introduce in mid 1990's for yield monitoring
- StarFire™ is an absolute positioning system that does not require base stations
- RTK Extend makes RTK solutions more robust



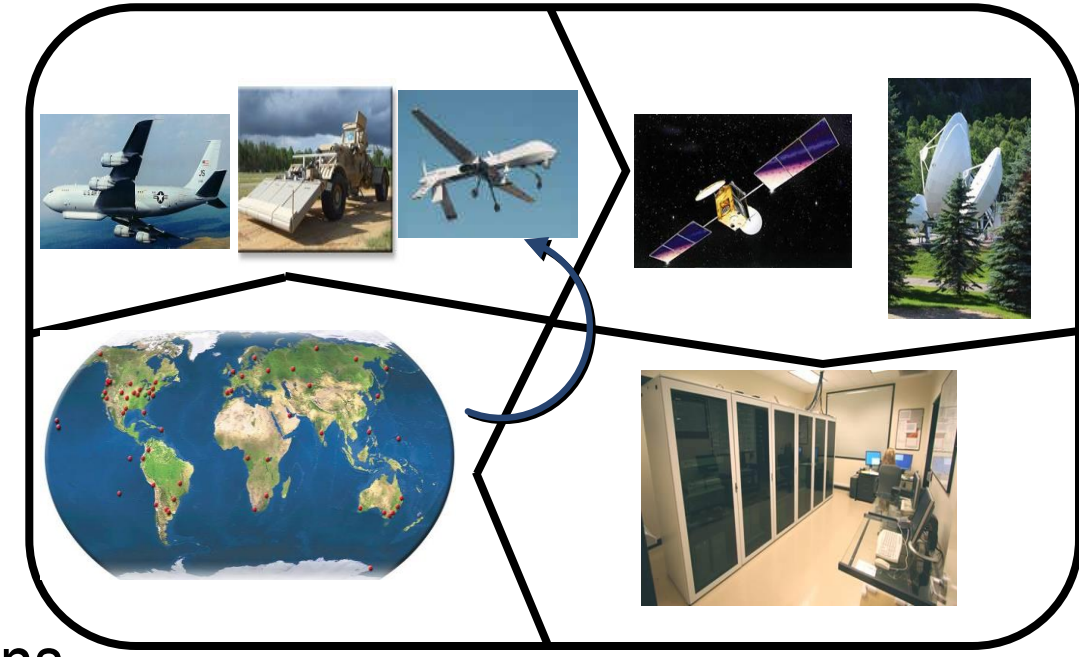
StarFire Global SBAS is a key enabler

- Deere needed a way to accurately position agricultural equipment in rural areas on a global basis
  - Accurate enough to automatically steer a tractor or a combine
- Solution needed to be simple and not require local infrastructure

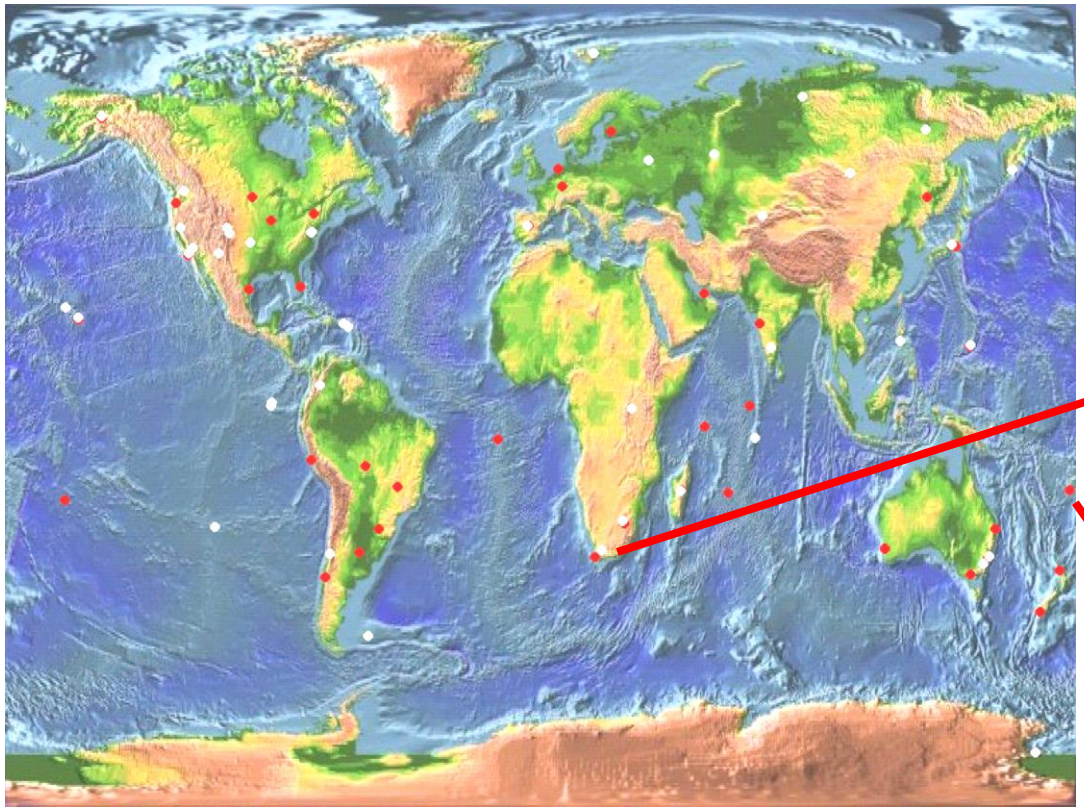
Whether your surveying
a 500 mile pipeline or
1000 miles at sea,
you still get 10 cm accuracy

StarFire Overview

- Worldwide network of reference stations
- Processing centers computes orbit & clock corrections
- StarFire channels on GEOs streams corrections to users
- Reliability and integrity



StarFire Reference Station Network



80+ Reference Stations

- 40+ Deere (in red)
- 40+ JPL (in white)

StarFire Processing Centers

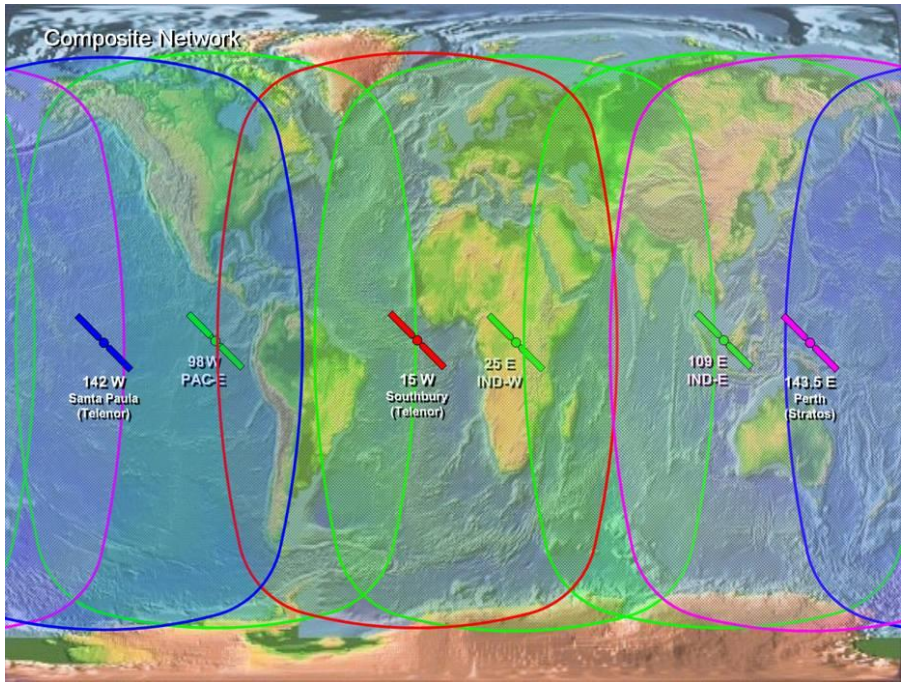
- Two fully redundant processing centers
  - Torrance, California
  - Moline, Illinois

- Both processing centers compute a correction stream for all GPS satellites
  - Orbit Corrections once a minute (Δxyz ECEF)
  - Clock Corrections once every two seconds
  - Master Clock - United States Naval Observatory

StarFire Uplink and Space Segment

- StarFire channels on global beams of 6 different L-band communication satellites
- All users see two StarFire signals from two channels
  - Americas –Laurentides, Canada
  - Americas – Santa Paula, CA
  - Europe – Burum, Netherlands
  - Europe – Southbury, CT
  - Asia – Perth, Australia
  - Asia - Auckland, New Zealand

Redundant Uplink Sites and Satellites



StarFire Receivers
Worldwide decimeter accuracy

SF-2040G
GIS Sensor

StarFire SF-3000

- Dual frequency GPS receiver
- Compensates for cab roll caused by uneven terrain
- Improves vehicle guidance and row-following

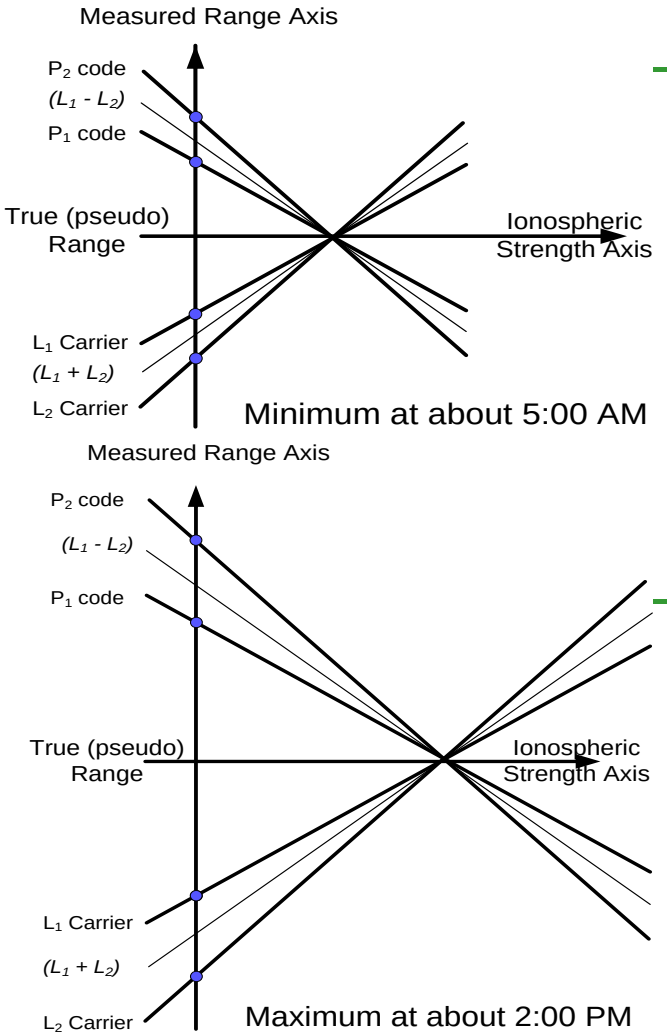
StarFire SF-2040 Series:

- Land survey

StarFire SF-3050 Series:

- for Offshore, Survey, Government markets

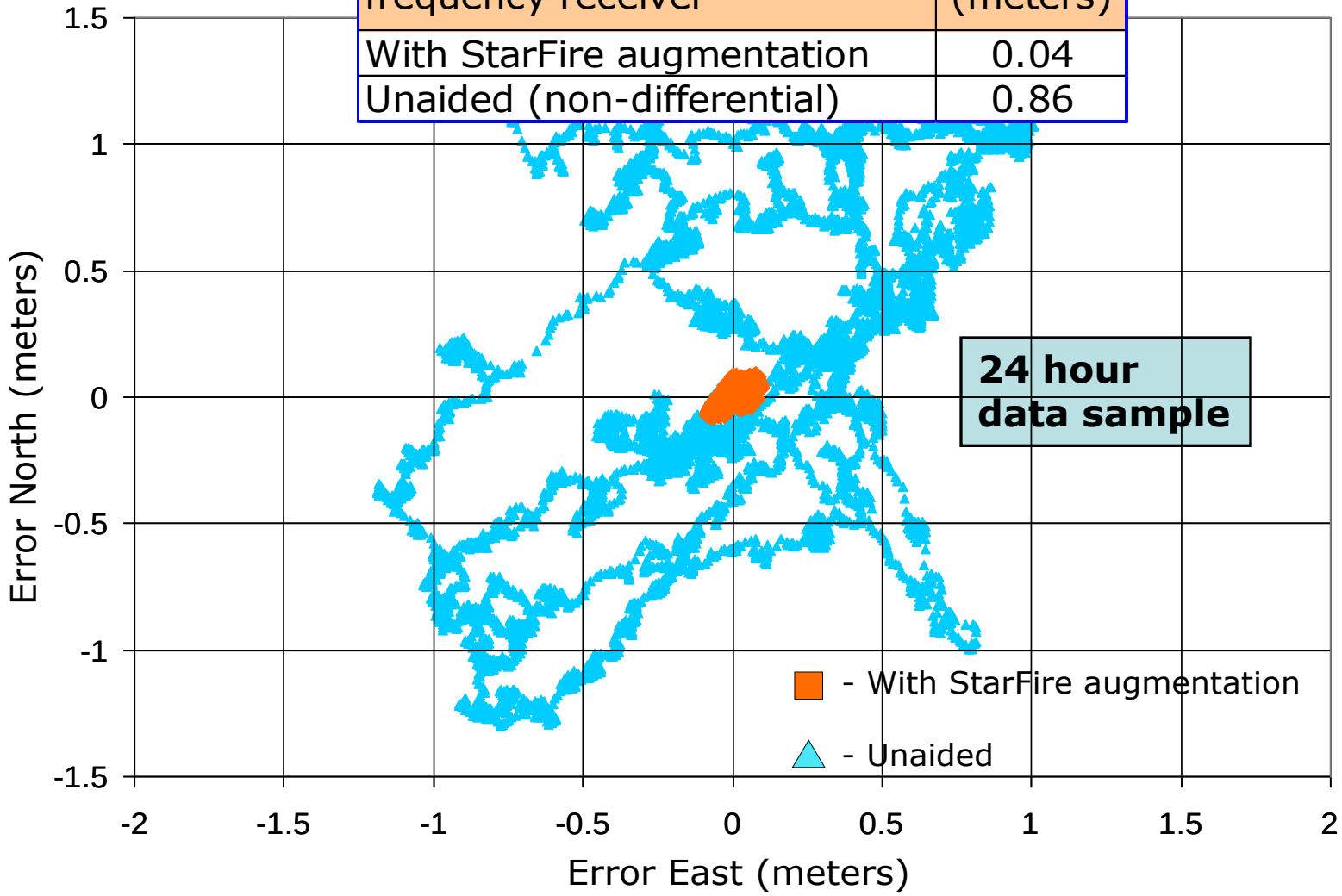
Ionospheric Refraction Effects



- **Problem:**
  - The ions in the upper atmosphere delay the code measurements (make them longer)
  - *But absorb and reradiate the phase (make them shorter).*
    - The effect is inversely proportional to the square of the frequency
    - *The effect varies significantly with the 11 year solar activity cycle*
- **Solution: Measure or Model**
  - Low cost receivers use measurements from a single frequency from the satellite and model the effect (The Klobachar model coefficients sent from satellites)
  - *High accuracy receivers use measurements from both L1 and L2 and combine them to make the measurements free from ionospheric effects*

StarFire and Unaided Horizontal Accuracy

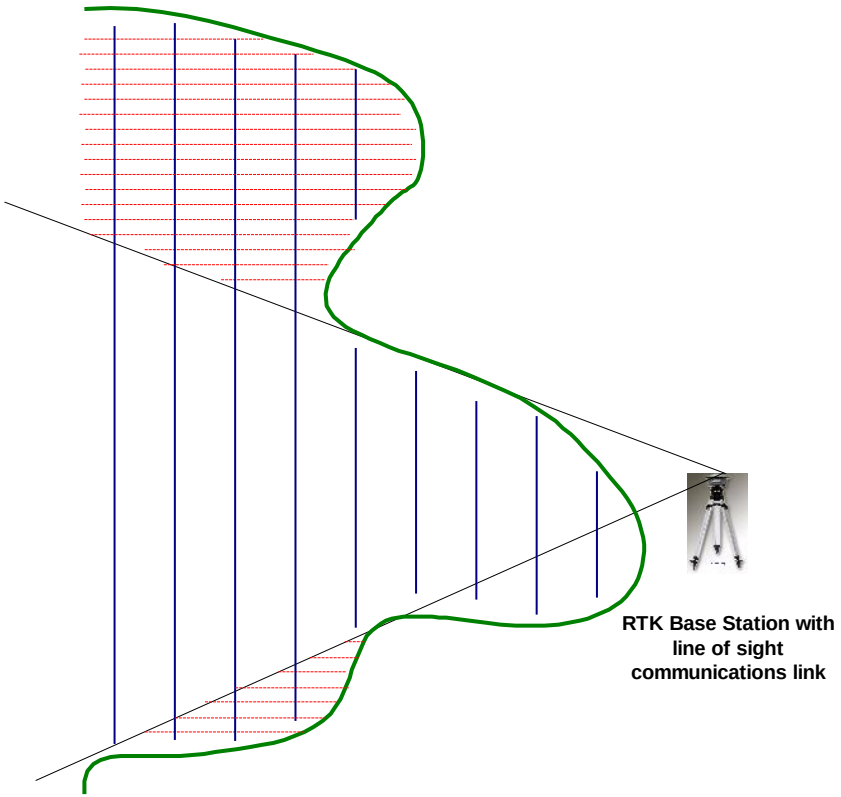
NavCom all-in-view dual frequency receiver	DRMS (meters)
With StarFire augmentation	0.04
Unaided (non-differential)	0.86



Additional Benefits from StarFire Augmentation

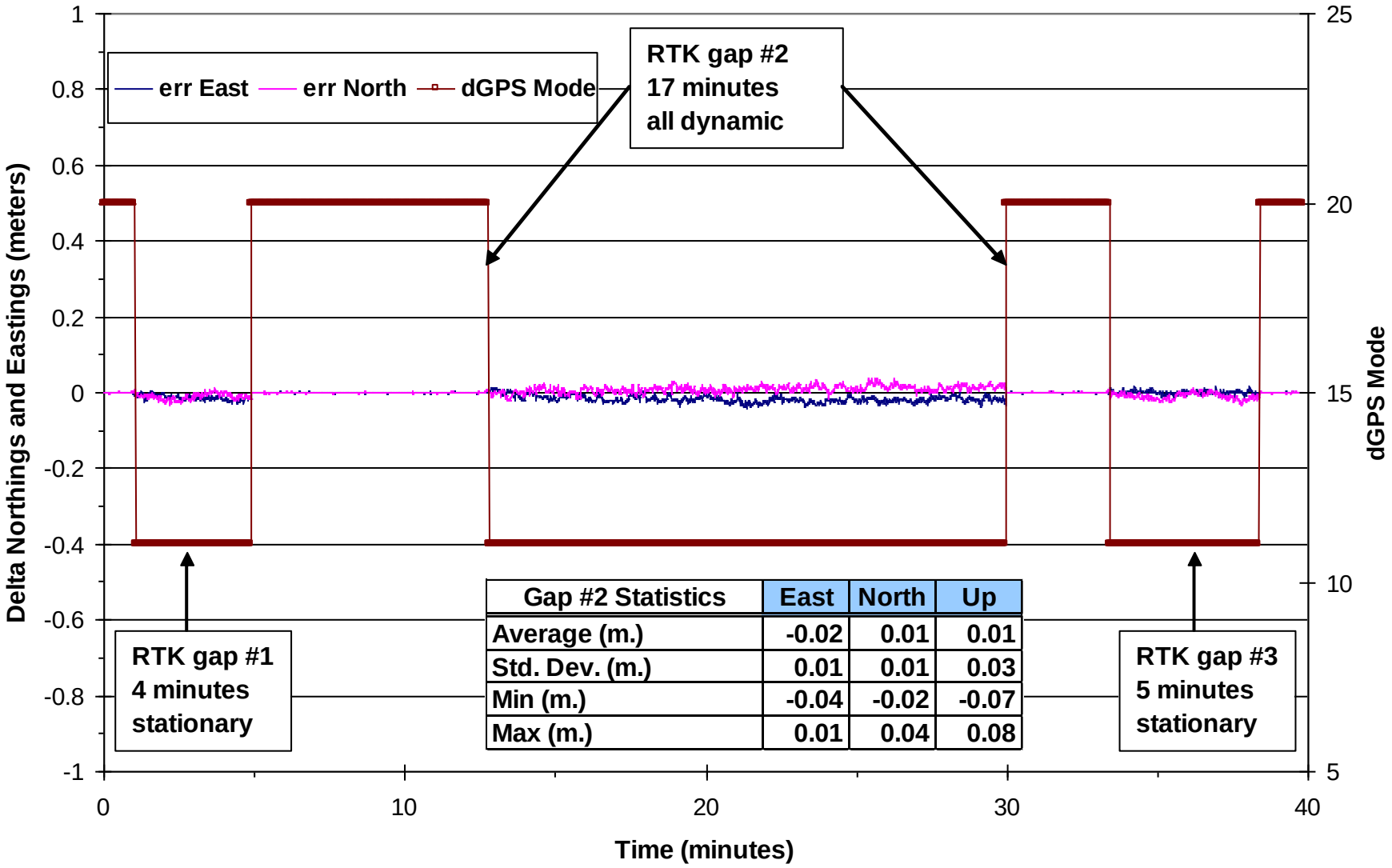
- Integrity monitoring
  - Broadcast correction stream contains validity flags for each satellite which are tightly monitored and controlled by the processing center software.
    - Most common satellite vehicle error, clock runoff, detected early – PRN 02 example from 2006
- RTK – extend
  - Proprietary technique which uses StarFire to bridge gaps in RTK coverage caused by range limits and data comm. gaps

RTK Extend



- When RTK is available use it to initialize the StarFire solution
- When RTK solution is lost use the StarFire solution (with offset) to coast through outages caused by loss of the communication link (e.g. hills or forest)
- Very small accuracy loss (low drift rate) and automatic RTK reacquisition

RTK-X Dynamic Test Results



Gap #2 Statistics	East	North	Up
Average (m.)	-0.02	0.01	0.01
Std. Dev. (m.)	0.01	0.01	0.03
Min (m.)	-0.04	-0.02	-0.07
Max (m.)	0.01	0.04	0.08

Applications

- Precision Farming
  - Yield Monitoring
  - Automatic Guidance
  - Water Management
  - Implement Positioning
  - Coordinated & Robotic Machines
- Other
  - Marine Survey
  - Land Survey
  - Military

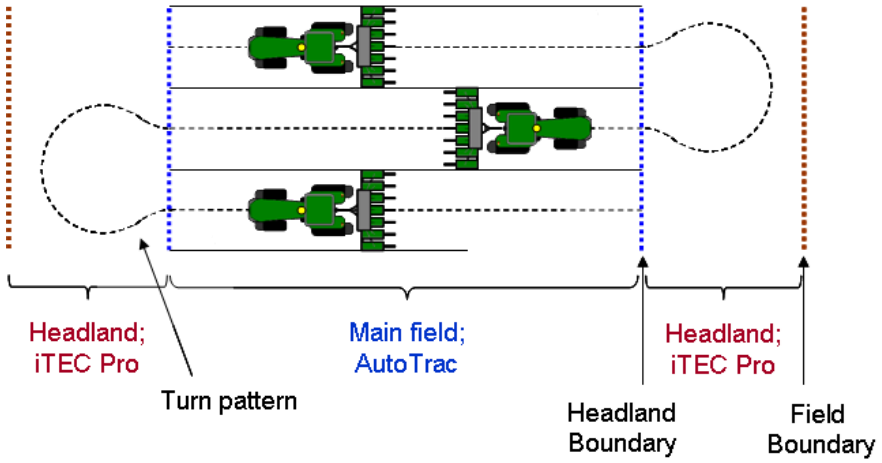
AutoTrac

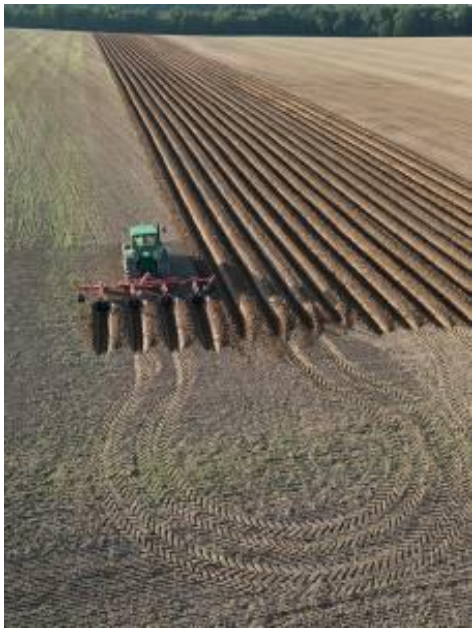
- Clear Customer Benefits:
  - Cut operator fatigue
  - Significant reduction in input costs (fuel, fertilizer, seeds, herbicides)
  - Reduce need for highly skilled operators
  - Operate in low-visibility conditions (more hours)
  - Faster speeds

Yield Mapping	Parallel Tracking	AutoTrac
1-2 meters	< 1 meter	Decimeter

iTec Pro (Intelligent Total Equipment Control)

- **Enables full automated in-field and headland operations:**
  - Automatic turn at the headland
  - Tractor speed & steering
  - Other implement & machine functions





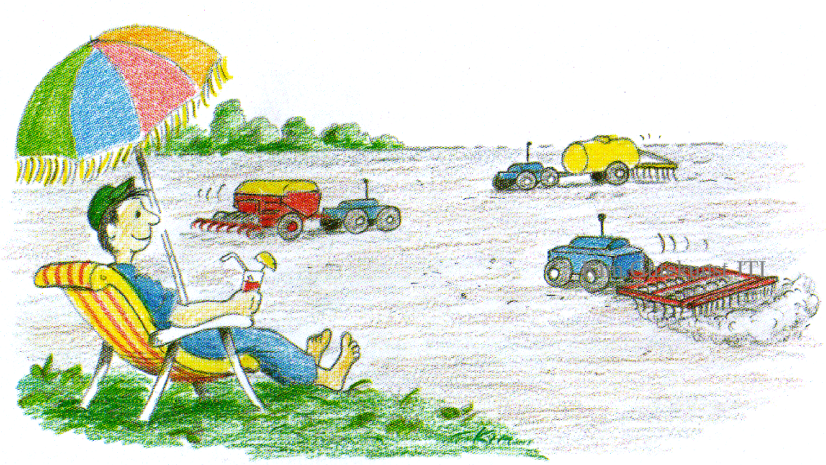
Agricultural Applications
Water Management

- Reduces installation time
- Reduces maintenance cost and time
- Portability

Coordinated and Robotic Systems in Agriculture

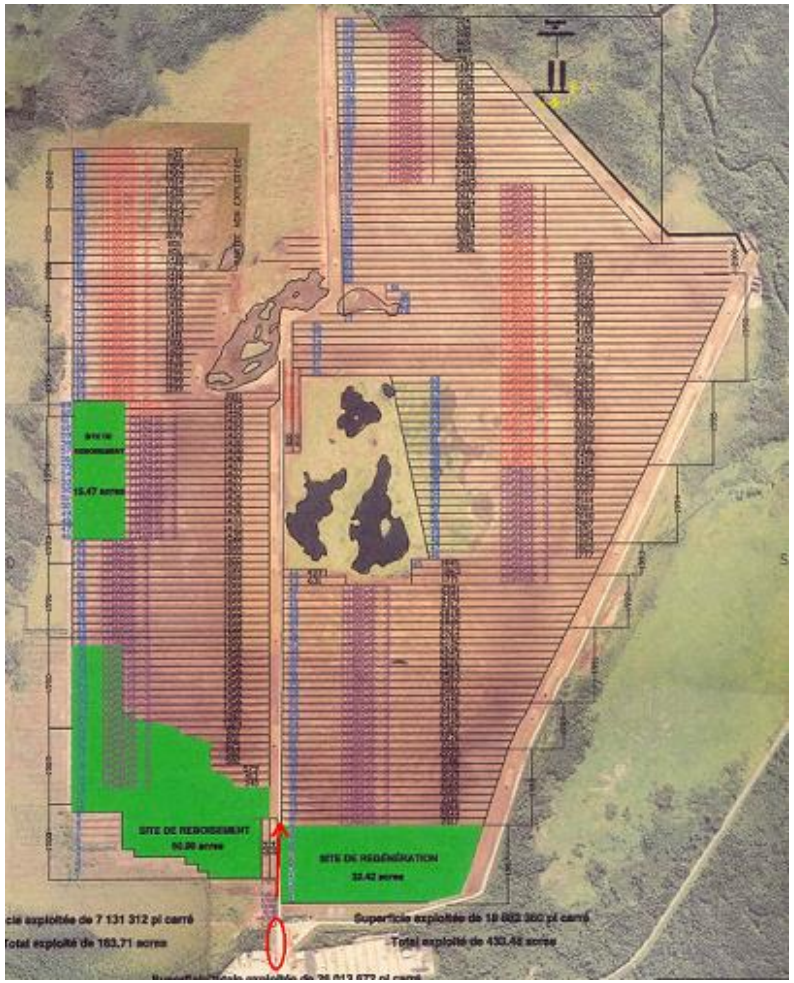
- General trend is to extend human capabilities through machine intelligence and information management
- In the next 10 years, expect a greater emphasis on robotics, extending to unmanned machines

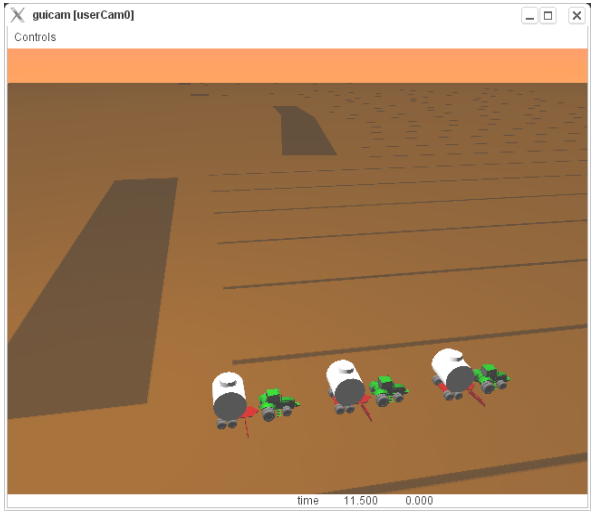
- Key non-technical barriers
  - Customer acceptance
  - Company acceptance
- Key technical barriers
  - Safeguarding
  - Navigation
  - Availability, accuracy & integrity



Coordinated Machines – Example

- Peat Moss Harvesting





Robotic Commercial Mowing

- Prototype autonomous professional mower in stadiums and golf courses
- Local positioning in GPS denied environments
- Complex path planning

NAVCOM
A John Deere Company

Robotic Orchard Tractor

- Explore opportunities to automate mowing, spraying and hauling
- Perception-based guidance
- Human detection

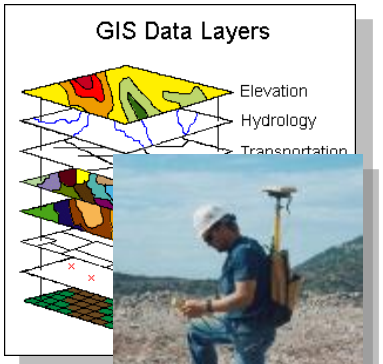
Robotic Security – R-Gator

- Deployments
  - Security patrol at SPAWAR
  - Airborne Assault Expeditionary Force
  - RS-JPO
- Customer Needs
  - Keeps soldiers out of harm's way
  - Transports supplies autonomously
  - Drop-Zone Ready

Agriculture & related markets
What will happen in the next 10 years?

- Unmanned systems will become commercially available
- Intelligent machines will increase system productivity
- New machine form factors
- First-to-market products will be semi-autonomous
- Wide-area differential GNSS system performance will continue to improve
- GNSS sensor fusion will enable new applications
- Safeguarding sensors more cost effective

Other NavCom Applications



Offshore Operations

Summary

The farm is being transformed by precise navigation

Efficiency and environmental considerations will continue to drive us toward automated farming

Thank you