Surveying using GPS Precise Point Positioning

O. Øvstedal, Norwegian University of Life Sciences
N.S. Kjørsvik, TerraTec A/S
J.G.O. Gjevestad, Norwegian University of Life Sciences

Outline

- Precise Point Positioning (PPP)
- General correction model
- Special issues related to PPP
- Development of operational software
- Results from projects
- Summary

Starting point is the Standard Navigation Service (SPS)

- Horizontal Precision of ≈ 3-5 m (95%)
- Major error sources
  - Ionosphere
  - Error in satellite clock corrections
  - Error in satellite coordinates and Earth Orientation Parameters.
  - Troposphere
  - Site dependent effects
    - » Loading
    - » Multipath
    - » Receiver noise
  - Satellite dependant effects
    - » Antenna offsets
    - » Yaw
  - ……..

Mitigation of error sources - I

Differential Processing

- One/several reference receivers operates at sites with known coordinates.
- Estimation of relative coordinates
- Accuracy depends on quality of receivers, observation method and sophistication of processing:
  - Meter
  - ...
  - ...
  - Sub-millimeter

Mitigation of error sources - II

Precise Point Positioning

- Use observations from one satellite receiver only
- Improved flexibility
- Reduced costs
- Global coverage with consistent and high accuracy
  - Static mode : centimeter
  - Kinematic mode : sub-decimeter

Correction model for PPP

- Precise satellite coordinates, earth orientation parameters and satellite clock corrections, available from e.g. International GNSS Service (IGS)
  - well defined formats
  - ftp-servers
  - free of charge
- Use dual frequency code **and** carrier phase observations
- Site dependant effects
  - Solid earth tide
  - Ocean loading
  - Receiver antenna calibration
- Satellite dependant effects
  - Satellite antenna calibration
  - Phase wind-up
- ……..

Take into account compatibility issues :

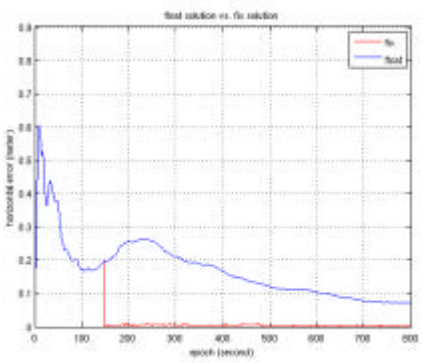
- **IERS and IGS conventions**

Handling of the tropospheric delay

- Correction model fed with apriori meteorological parameters (temp, pressure, humidity)
  - standard atmosphere
  - look-up table
- Correction model fed with meteorological observations of temp, pressure, humidity
- Estimation of residual tropospheric delay in the adjustment process.
  - Zenith delay
  - Gradients
    - Geometrical considerations

Special issues related to PPP

- Time-span of continuous observations
  - Hardware-biases in receiver and satellites make it necessary to estimate carrier phase ambiguities as real numbers in PPP
    - Float solution
    - Accuracy improves with time



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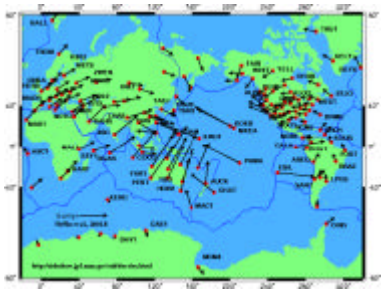
  - Precise satellite coordinates from IGS are in the last version of International Terrestrial Reference Frame (ITRF) at ***current epoch***.

"Global coordinates are time dependant"



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  - For most applications it is necessary to transform to regional or national reference frames, e.g. ETRF89.

Special issues related to PPP - II

- Latency of orbits and satellite clock corrections from IGS
  - Using IGS-products, PPP is presently a post-processing method
    - IGS is working towards real-time products
  - Real-time solution developed by JPL is used in some commercial solutions
    - NAVCOM
    - FUGRO XP

Development of an operational PPP software

- In-house software ***ABSPOS*** developed at Norwegian University of Life Sciences
  - Successfully used in several projects
  - Extensively tested by Hydrographic Survey of Norway
    - Accuracy
    - Reliability
  - Used as sole solution by Hydrographic Survey of Norway in high precision seafloor mapping from 2004.
  - Increased interest from operators in airborne photography and laser scanning
- Commercialisation by the Norwegian company TerraSat
  - ***TerraPos***

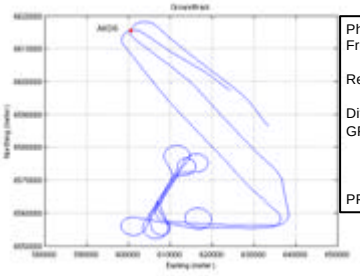
Handling of effects relevant to PPP in TerraPos

Effect	Method
Satellite antenna offset and phase center variations	Official IGS antenna calibrations
Satellite hardware biases	Official IGS calibrations, estimation of system specific effects.
Satellite yaw	Nominal model, user definable during eclipses and noon-turns, e.g. editing or stochastic correction.
Ionospheric delays Tropospheric delays	Ionosphere-free linear combinations Apriori models, estimation of residual effects
Receiver antenna offsets and phase center variations	Official IGS calibrations
System specific receiver hardware biases	Estimation
Solid earth tides Ocean loading Rotational deformation due to polar motion	Model recommended by the IERS Model recommended by the IERS Model recommended by the IERS

Typical accuracy (RMS) when processing data of high quality

Dynamics	Duration (hours)	Horizontal (meter)	Vertical (meter)
Static	24	0.01	0.02
	6	0.02	0.04
	1	0.05	0.10
Kinematic	24	0.03	0.04
	6	0.03	0.05
	1	0.15	0.20

Camera&GPS&INS calibration flight



Photogrammetric Testnet Fredrikstad.

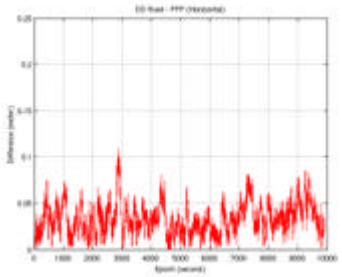
Reference receiver in AK06

Differential processing with the GPSPROG software
- fix-solution
- IF observable

PPP processing with TerraPos

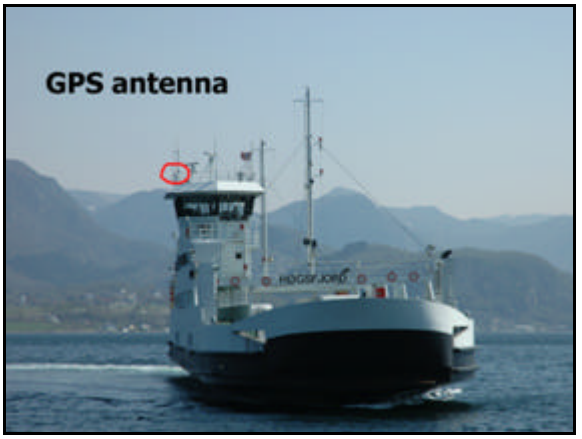
Camera&GPS&INS calibration flight

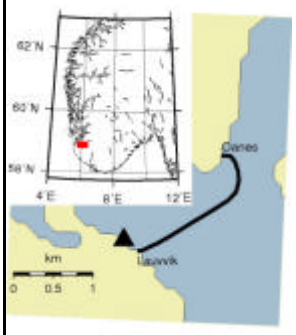
Differences between PPP and differential processing



Marine test

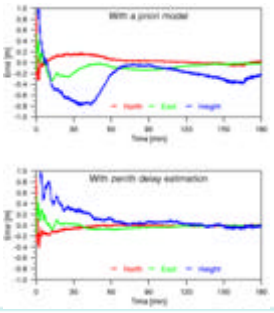
- Large scale test carried out by the Norwegian Hydrographical Service
- Topcon Legacy GNSS receiver on a shuttle ferry as well as in a reference station on land
- 40 days of continuous observations at 1Hz in March-May, 2006.
- Differential Real-Time Kinematic (RTK) solutions were recorded along with raw data.
- Differential post-processing with Geogenius v.2.11 from Spectra Precision Terrasat in 24 hour batches.
- Quality criteria
  - Only fixed solutions accepted (resolved double difference ambiguities)
  - 3D discrepancy between RTK and post processing smaller than 0.02 m
- Final reference trajectory computed as average solution between RTK- and posts processed solution.





Map showing the test area in south-west Norway.
The ferry shuttles along the solid black line. The reference station used to compute the reference trajectory is shown with a triangle.

Sequential filter processing only



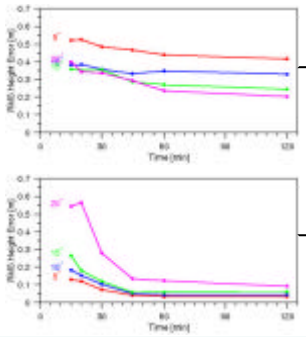
Processing strategies

- With and without ZTD-parameters
- Different weighting functions
  - Constant weights
  - 1/sin(elev)
  - Standard model of TerraPos (composite model)
- Different elevation cut-off angles
  - 5°, 10°, 15°, 20°
- Different time spans of the 12 hours observations were processed in stepwise windows of
  - 15 min, 20 min, 30 min, 45 min, 60 min and 120 min

12 combinations

12 hours of 1Hz data were processed in 3408 program runs (filter + smoother solutions).
Overall RMS values were computed for the 12 strategies and presented as function of time span.

The following plots show the height component only.



In the end……

Using a state-of-the-art PPP software for kinematic processing of "high quality" GPS observations:

- height coordinates at the sub-decimetre level is reached after approximately 30 minutes (one sigma)
- height coordinates at the sub-decimetre level is reached after approximately 60 minutes (two sigma)
- the accuracy consistently improves with length of time span of continuous observations
- the use of low elevation observations (e.g. down to 5 **°**) is beneficial