

# Precise Satellite Positioning: Challenges and Prospects

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## Twenty Years of Progress: Where do we go from here?

☞ *Carrier phase-based GPS positioning techniques have come a long way.*

*Centimetre level positioning now possible:*

- q Kinematic positioning
- q Instantaneous mode
- q Real-time results
- q Baselines from 10s to 1000s km
- q Comparatively low-cost hardware
- q Many applications



## Challenges? Addressing Technical Constraints

- ❑ Communications & real-time operation
  - q COTS products & their performance limits
  - q Matching "plug & play" capabilities of current DGPS systems
  - q Baseline length dependent factors that influence accuracy
  - q Addressing special or new applications

*F One of the greatest technical challenges is supporting cm-level accuracy positioning over variety of baseline lengths.*



## Part 1: Short-Range GPS/Glonass Positioning

- ☞ *"Short-range" implies that distance-dependent errors after differencing between two receivers can be ignored for ambiguity resolution purposes ... <10km for "standard" survey & precise navigation applications*
- q Functional models and stochastic models
- q Ambiguity resolution and validation procedures
- q Achievements and remaining challenges



# Functional Model Challenges

*Basic GPS modelling for cm-level positioning is now well understood ... some challenges remain in relation to maximising accuracy performance with minimum data*

- Integrated GPS+Glonass(+INS) processing
- Single-epoch ambiguity resolution (*for the above*)
- Special navigation applications, such as attitude determination
- Robotic & guidance applications
- Non-positioning applications, such as meteorological, ocean reflected signal analysis, etc.



# Functional Model: Instantaneous Ambiguity Resolution

*Implies single-epoch carrier phase-based positioning ... not yet implemented in COTS products ...challenge is reliable and validated AR results*

- All observations at an epoch used to determine ambiguity-float solution.
- Integrated, optimal search procedure using LAMBDA method.
- Fast, efficient computational technique for real-time use.
- Careful attention to functional & stochastic modelling, QC/QA and AR result validation.



# Modelling or Otherwise Accounting for Biases

- ☞ *Reliable results depend on the correct mathematical model ... much R&D in recent years.*
- q Residual biases for double-differenced functional model:
- *residual atmospheric delay & orbit error*
  - *multipath disturbances*
  - *outliers*
  - *others?*
- q Stochastic model for measurement noise AND residual biases (above).
- @ *Challenge:* For reliable AR, need to mitigate or account for these biases in functional model or stochastic model.



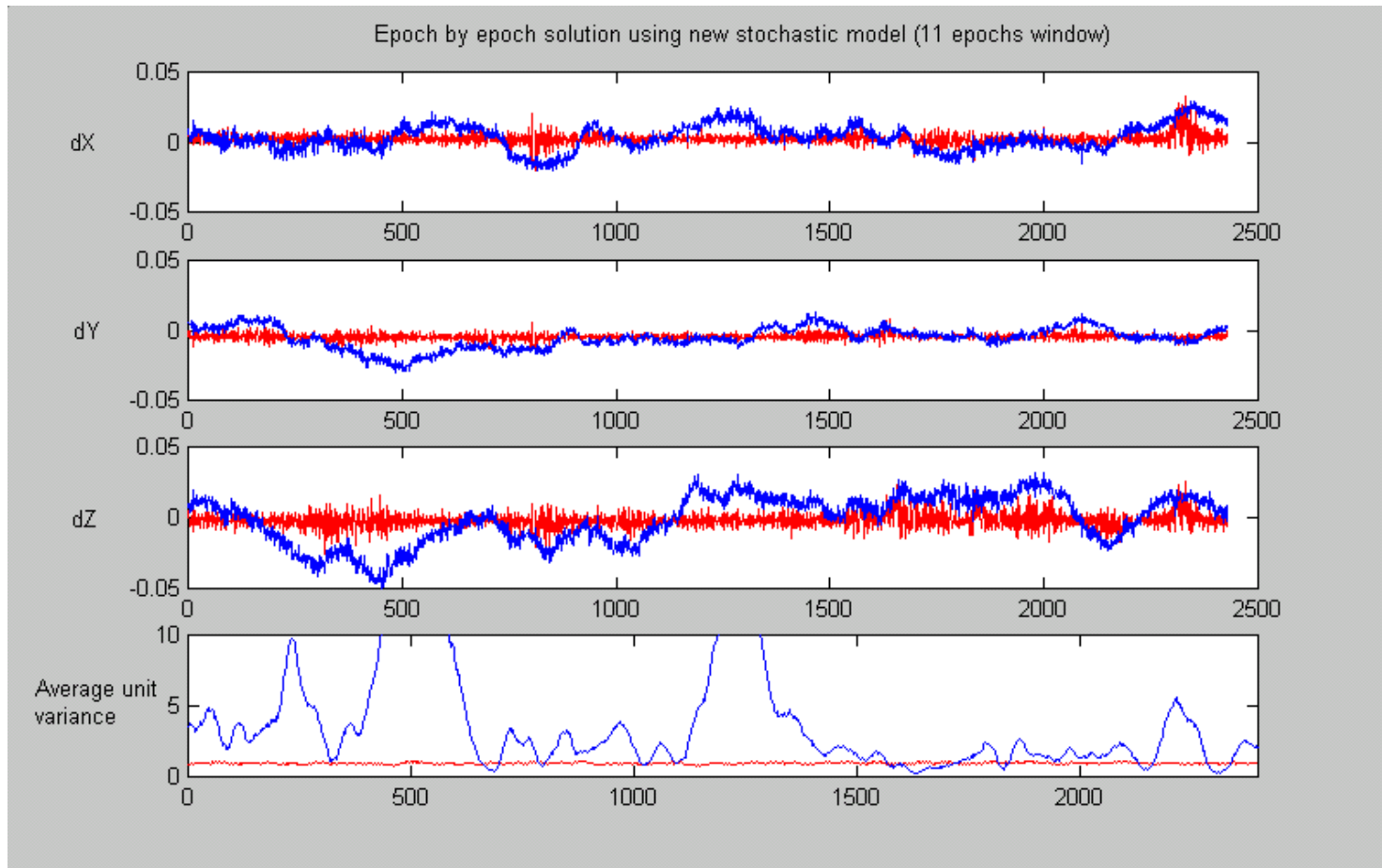
# Stochastic Model Improvement

- ☞ *Current "hot" research topic to improve reliability of AR, and for more effective QC.*
- q More complex noise modelling of GPS observations
  - q Empirical techniques to account for site dependent effects
  - q Need to account for temporal correlations
  - q Need to account for spatial correlations
  - q Use adaptive techniques suitable for real-time processing

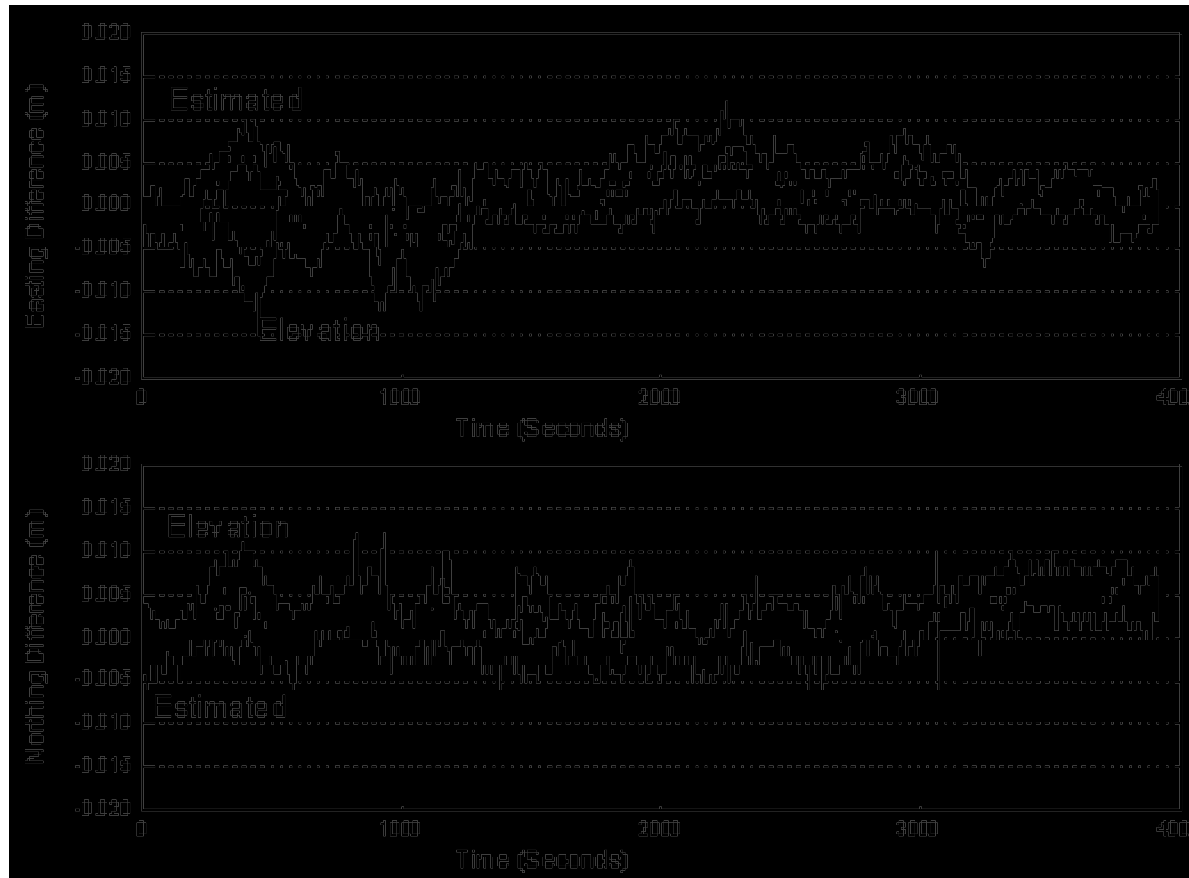
*Current COTS systems are relatively "primitive" in terms of stochastic modelling, hence performance suffers when conditions are not ideal.*



# Importance of Stochastic Model



# Horizontal component differences for the different stochastic models



# UNSW Integrated GPS/Glonass Data Processing Strategy

## Functional Model -- integrated functional model

- Reliable ambiguity resolution, no significant impact of residual biases.
- Account for clock & instrumental biases through appropriate processing strategy using ALL data.

## Stochastic Model -- empirical stochastic model

- Site/environment dependent model.
- consider all remaining biases in a stochastic fashion.
- consider spatial correlation of observations.



# Ambiguity Resolution Techniques

- Fast ambiguity search techniques:
  - Search in the observation domain  
Abidin, 1993; Han, 1995; Goad, 1992; Teunissen, 1996; Wubben, 1989
  - Search in the coordinate domain  
Han, 1994; Lachapelle et al, 1992; Mader, 1992; Remondi & Hilla, 1993
  - Search in the estimated ambiguity domain or transformed ambiguity domain  
Chen & Lachapelle, 1995; Frei et al, 1993; Han & Rizos, 1995; Hatch, 1990; Landau & Euler, 1992; Teunissen, 1994
  - Integrated search methods  
Han & Rizos, 1996; Abidin, 1993

*AR technique R&D is adequate ... challenge is reliable AR even when conditions of data, satellite visibility & site observing quality are not ideal.*



# AR Validation Procedures

☞ *Technical advances: statistical testing, use of apriori information/constraints, iterative techniques, use of redundant observations ... procedures implemented in an integrated fashion within UNSW software:*

- q Careful AR validation criteria
- q Eliminating satellites, *starting with lowest elevation*
- q Implementing outlier detection technique(s)
- q Reweighting suspect observations
- q Applying any external information where available, *e.g. TEC series, epoch-by-epoch series, etc.*



# Concluding Remarks for Short-Range Case

- Dual-frequency GPS receivers can deliver centimetre accuracy position in real-time, and under good conditions even with a single epoch of data.
- Single-frequency GPS/Glonass receivers can deliver better positioning reliability, integrity, and availability than single-frequency GPS receivers.
- Dual-frequency GPS/Glonass receivers provide best positioning reliability, integrity, and availability.
- The positioning/AR reliability may not be good enough for all applications. *Special operational procedures may be necessary for critical applications.*

***In short, the technical challenge is the refinement of the functional and stochastic models, and the implementation of quality control procedures.***



## Part 2: Medium-Range GPS Kinematic Positioning

☞ *The distance dependent errors cannot be ignored, but can be modelled using multiple reference stations for efficient AR ... new area of R&D for which no COTS presently available .*

*Although GPS permanent stations are being increasingly established all over the world for specific purposes, they could support multiple applications:*

- **GPS kinematic positioning over medium-range baselines (10-100km)**
- **rapid static positioning system using low-cost GPS receivers**
- **machine control & deformation monitoring applications**
- **Pseudo-range-based DGPS**
- **Non-positioning applications**



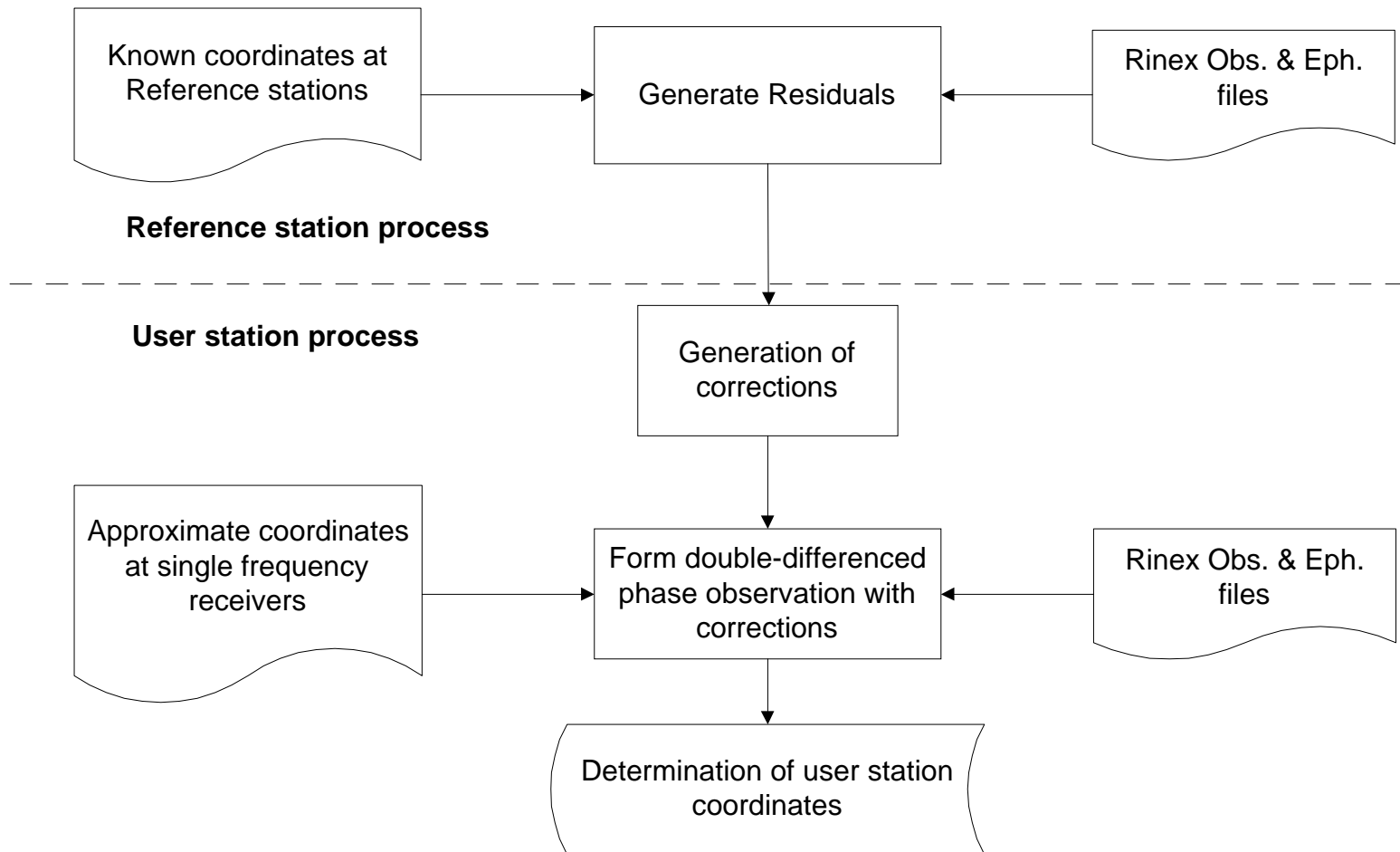
# Linear Combination Model

In the UNSW technique, linear combinations of single-differenced observations from the user receiver to multiple reference receivers are formed:

- *Orbit bias accounted for.*
- *The ionospheric delay reduced using an epoch-by-epoch, satellite-by-satellite ionosphere model.*
- *The tropospheric delay reduced by interpolation to regional model after applying apriori troposphere corrections.*
- *The multipath at the reference receivers mitigated by weighted averaging.*
- *The observation noise mitigated by weighted averaging.*



# Flow Chart of Data Processing Procedure



# Instantaneous Ambiguity Resolution Procedure

- ➔ *Integer ambiguities can be resolved using a single epoch of data for medium-range GPS kinematic positioning ...*
- Integrated functional model - using precise pseudo-ranges and carrier phase observations on L1 and L2 with "network correction terms".
  - Real-time stochastic model estimation - adaptive improvement of stochastic model based on the immediate past data.
  - New integer ambiguity validation procedure, real-time fault detection and adaptive procedure.
  - *Similar results can be achieved to that of the short-range case.*

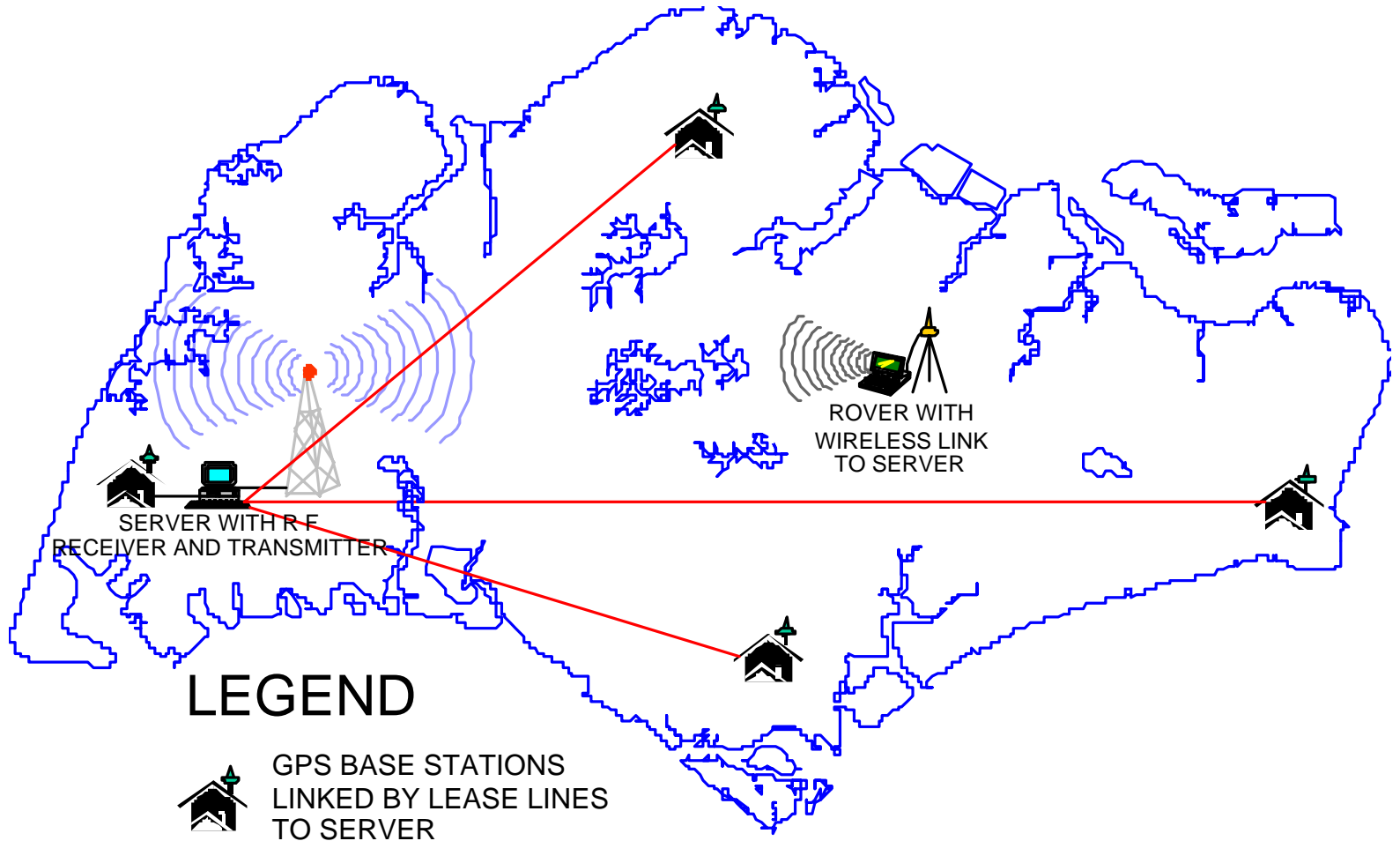


# Concluding Remarks for Medium-Range Case

- A linear combination functional model has been developed in which orbit biases and ionospheric delay terms can be eliminated, and in addition, the tropospheric delay, multipath and observation noise can be reduced.
- Similar results to the short-range case have been achieved.
- The challenges include:
  - **How to compute network correction terms in real-time, e.g. implementing real-time AR for reference stations over regional scale areas?**
  - **How to compute, transmit and apply corrections for different user applications?**

***This requires extensive testing and evaluation on an appropriate test facility ...***





## Part 3: Long-Range GPS Kinematic Positioning

☞ *The distance-dependent errors cannot be estimated or eliminated to allow reliable OTF-AR ...*

- Absolute ambiguity resolution on-the-fly for long-range kinematic positioning is a very difficult task.
- Preferred option is "relative" on-the-fly AR (i.e. resolve cycle slips), by recovering integer ambiguities using "ambiguity recovery" technique (Han, 1995).
- Specialist applications in airborne positioning, buoy positioning, etc.



# Comments to Long-Range Case

- Technique needs initialisation of AR at start (*and perhaps at end also*).
- Data gaps greater than about 5 minutes very difficult to "bridge" using ambiguity recovery technique.
- Operational issues are significant, *especially for real-time implementation*.
- Demonstrated sub-decimetre accuracy over baselines up to 1000kms in length.
- Unlikely to be developed as a commercial product, *different applications offer different possibilities of optimising procedures*.



# Summary: Technical Challenges & Prospects

- For short-range techniques, the technical challenge is the refinement of the functional & stochastic models, and the implementation of validation & QC procedures, *ultimately leading to reliable single-epoch positioning.*
- For medium-range techniques, multiple reference station procedures offer the greatest promise, *delivering similar performance to short-range techniques.*
- Dual-frequency techniques will always be superior to single-frequency ones, *but there is room for performance improvement.*
- GPS+Glonass positioning is more robust and reliable than GPS-only or Glonass-only, *but what are the prospects for Glonass?*
- Precise long-range kinematic positioning is feasible, *but is operationally complex and will continue to challenge GPS researchers.*
- Modernisation proposals for GPS and the new Galileo system offer exciting opportunities to challenge some of the current constraints through improved signals, *but such systems are unlikely to impact for another decade.*

