Resource Assessment for Hydropower Installations in the Ocean on the Basis of Spaceborne Radar Interferometry

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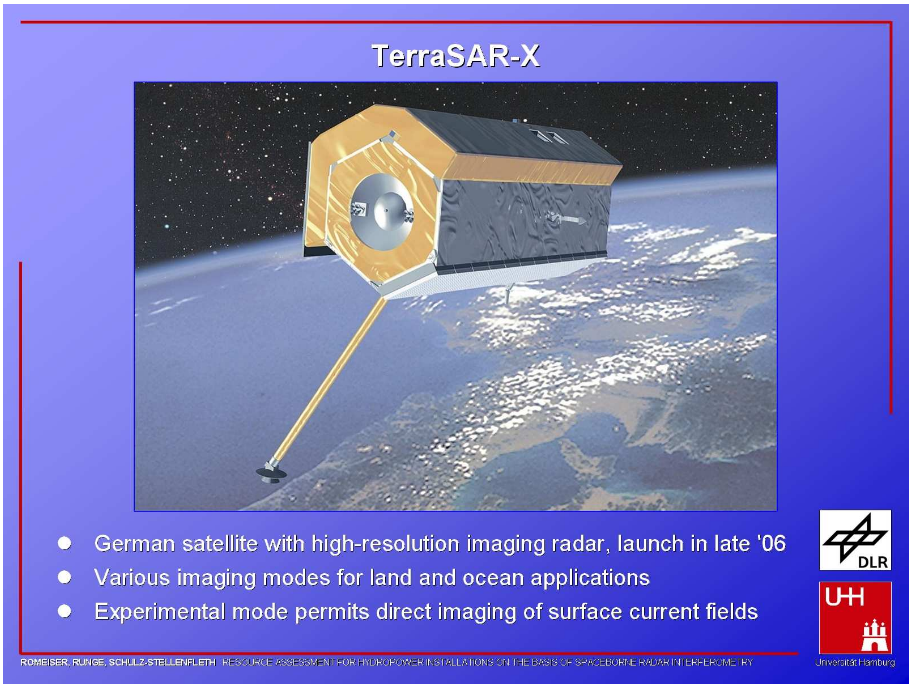
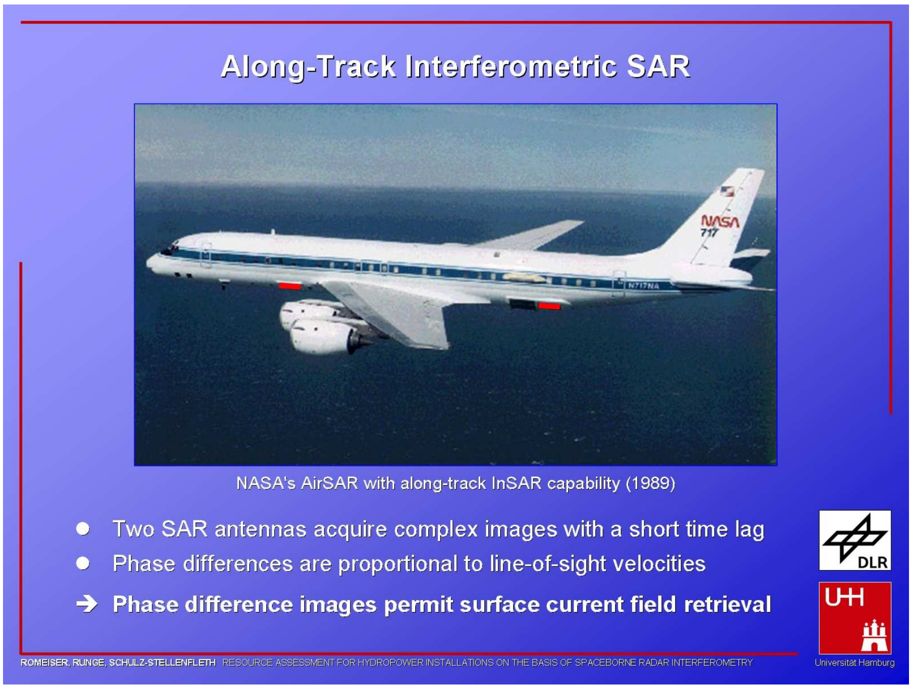
The siting and resource assessment for hydropower installations in the ocean, which exploit tidal currents for the generation of electric power, as well as the analysis of environmental effects of such installations, requires detailed information on the spatial and temporal variations of tidal currents. Until now, such information has been obtained mainly from in-situ measurements and numerical simulations. We would like to promote the use of a satellite-based remote sensing technique, which will become available for operational use in the near future. A combined use of circulation models, in-situ data, and satellite data will permit dynamical analyses with unprecedented spatial and temporal coverage and resolution.

Slide 3: The first satellite to offer current measuring capabilities will be the German TerraSAR-X, which is scheduled for launch in late 2006. TerraSAR-X can take conventional high-resolution synthetic aperture radar (SAR) images of land and ocean surfaces for a variety of applications in several different modes of operation. In an experimental mode, the radar antenna panel with a total length of 4.8 m can be split into two independent parts for receiving. This antenna arrangement will permit a direct imaging of surface current fields by a technique called along-track interferometric SAR (along-track InSAR).



Slide 3

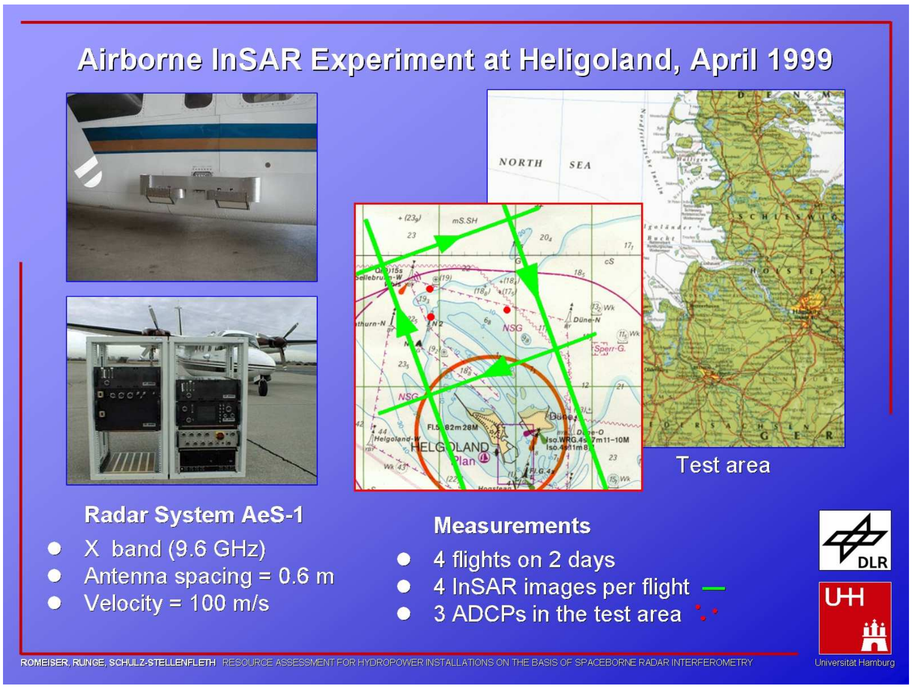
Slide 4: A first airborne along-track InSAR was flown by NASA-JPL in 1989. An along-track InSAR uses two radar antennas separated by some distance in flight direction to acquire two images of the same scene from the same antenna location with a time lag of a few milliseconds. The time lag is determined by the along-track distance between the antennas and the flight velocity.



Slide 4

The along-track InSAR technique exploits the fact that two complex SAR images acquired with a short time lag exhibit phase differences proportional to the Doppler shift of the backscattered signal and, thus, to the line-of-sight velocity of the scatterers. This way, a direct imaging of surface velocity fields with the high spatial resolution of a SAR on the order of meters becomes possible.

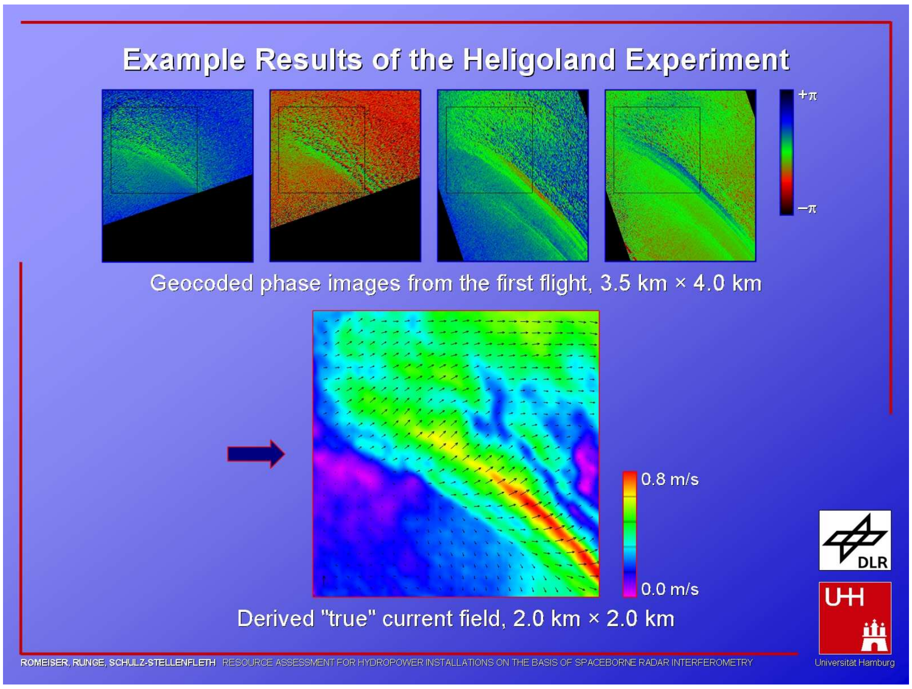
Slide 5: In 1999 and 2001, the University of Hamburg and Aero-Sensing GmbH performed two airborne along-track InSAR experiments in the German Bight of the North Sea. The figures show the InSAR hardware and the test area over an underwater reef northwest of the island Heligoland with four flight tracks arranged such that two perpendicular current components were measured from two opposite directions. Four flights were performed at different tidal phases within two days. Reference data were obtained from three bottom-mounted acoustic Doppler current profilers (ADCPs).



Slide 5

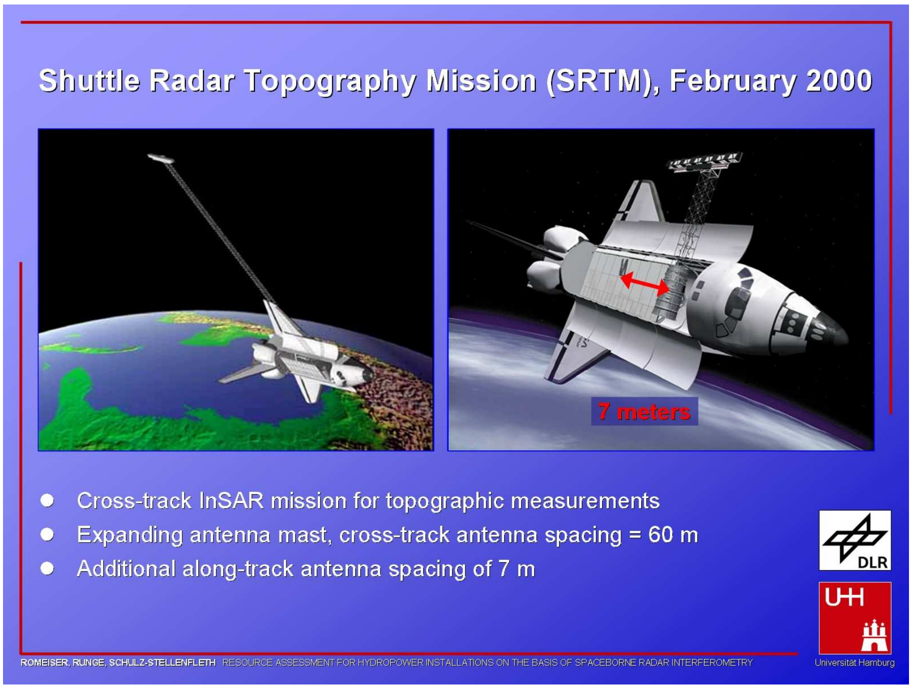
Slide 6: The figures show the four InSAR phase images obtained during the first flight at Heligoland and the surface current field derived from these data. This current field covers an area of 2 km × 2 km with a grid resolution of of 20 m × 20 m. The strong currents over the underwater reef are resolved very well. The InSAR-derived currents are consistent with the ADCP data and with results of a numerical circulation model.

Slide 6

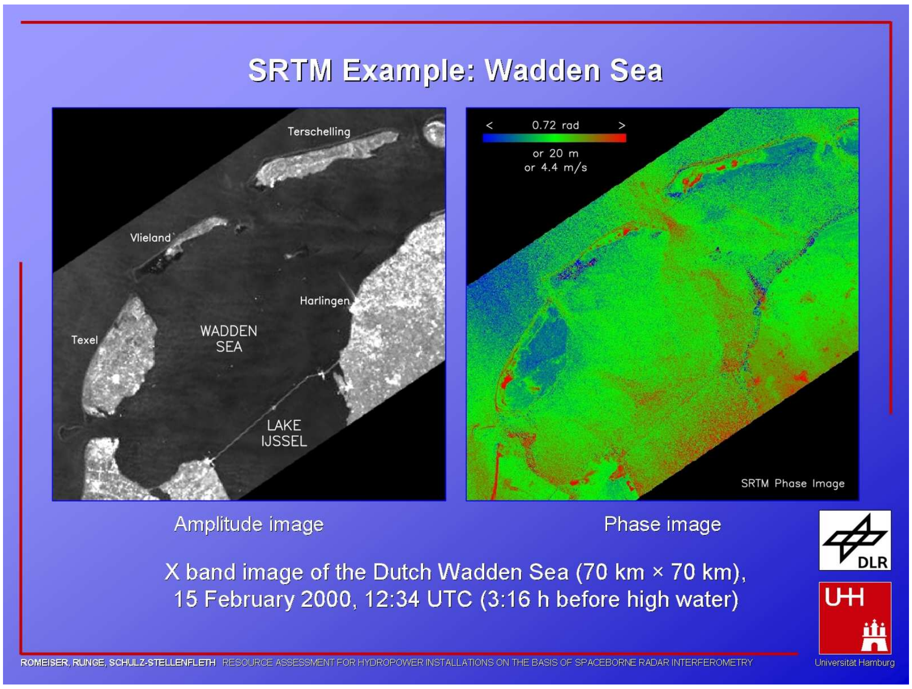


Slide 7: A first demonstration of current measurements from space could be given with data from the Shuttle Radar Topography Mission (SRTM) in February 2000. Mainly designed for a global survey of the earth's land topography, SRTM used an InSAR with a cross-track antenna separation of 60 m. However, an additional along-track separation of 7 m resulted in an additional sensitivity to target velocities.

Slide 7



Slide 8: The figures show amplitudes and phases of an SRTM image of the Dutch Wadden Sea obtained on 15 February 2000. The shown area size is 70 km × 70 km.



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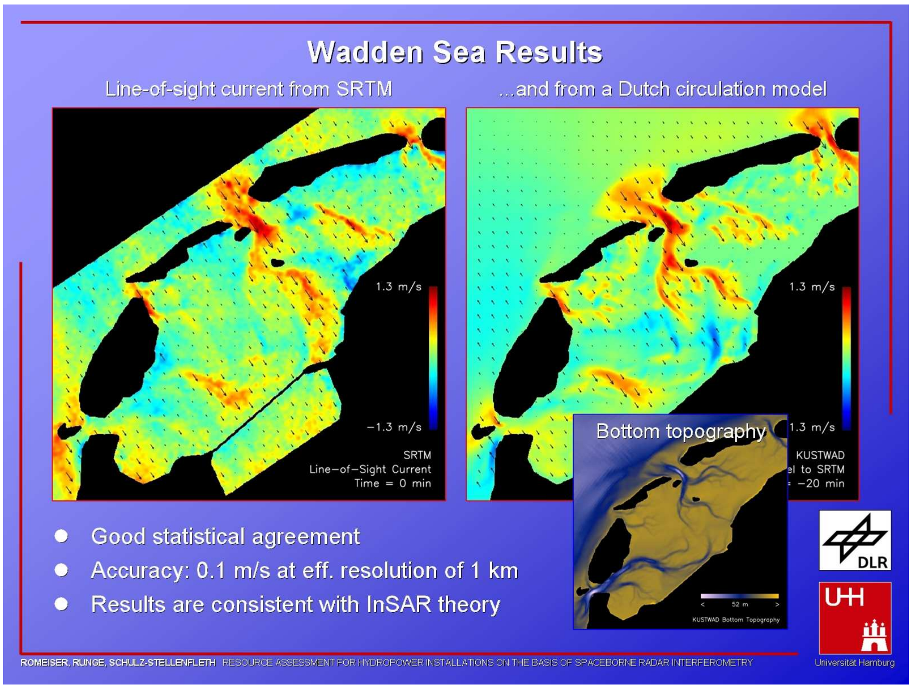
Slide 9: SRTM-derived line-of-sight current field in the Wadden Sea (left) and corresponding theoretical current field from a numerical circulation model (right).



Slide 9

The flow patterns and strengths in both current fields are very similar; the smaller figure at the bottom shows that they are strongly correlated with the bathymetry. A statistical analysis has shown that the SRTM-derived currents have an RMS error of less than 0.1 m/s at an effective spatial resolution of about 1 km, which is consistent with theoretical expectations. In view of the fact that SRTM was not designed for current measurements this is a quite positive result.

Also TerraSAR-X is mainly designed for land applications; along-track InSAR capabilities will be available in an experimental mode only. TerraSAR-X uses the same radar frequency band as SRTM (X band, 9.6 GHz), but the effective along-track distance between its antenna halves is a factor of 1/3 shorter than the along-track distance between the two SRTM antennas, and the instrument noise level is about 10 dB higher. Both facts lead to further increased phase noise; more averaging of individual pixel values will be required for noise reduction. However, this problem is partly compensated by the fact that TerraSAR-X has much better spatial resolutions than SRTM, thus more pixels will be available for averaging within a given area.

TerraSAR-X has three different basic imaging modes:

– the conventional "stripmap" mode with a swath width of 30 km and a nominal spatial resolution on the order of 3 m,

– the "ScanSAR" mode with an increased swath width of 100 km but a reduced resolution on the order of 16 m, and

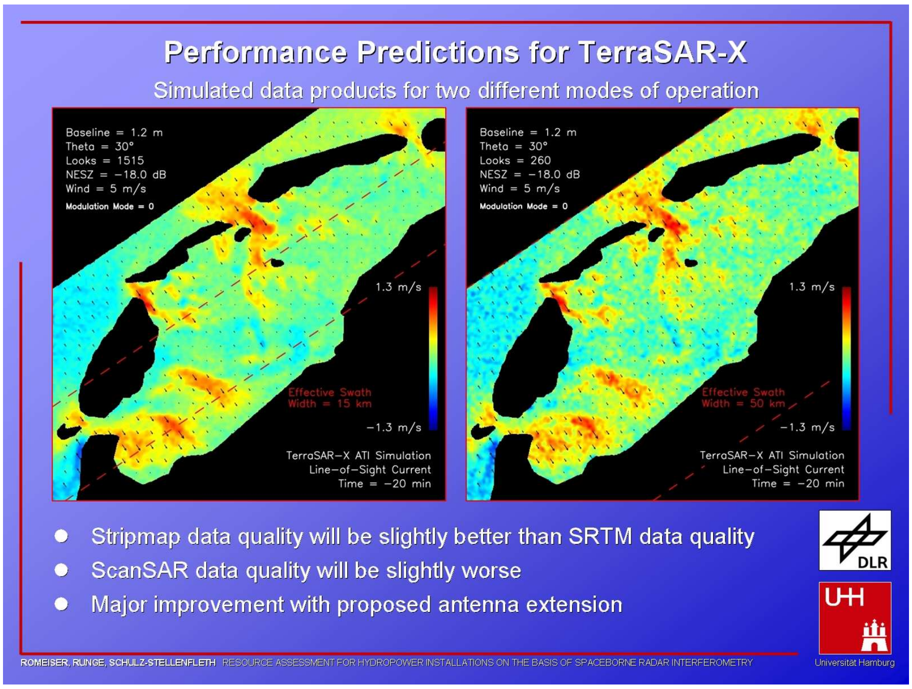
– the "spotlight" mode with a very high resolution of 1-2 m (over land) but a limited image size of 10 km × 10 km.

Technically, the stripmap mode is the favorable mode for along-track interferometry. Depending on the receiver settings, the effective swath width for data acquisitions in split-antenna mode may be limited to 15 km (50 km in ScanSAR mode).

TerraSAR-X will be in a sun-synchronous orbit at an altitude of about 500 km with an orbital period of about 100 minutes and a repeat cycle of 11 days, i.e., repeated images of the same scene from the same look direction can be acquired every 11 days.

Slide 11: In a recent study by the University of Hamburg and DLR, the current measuring capabilities of TerraSAR-X in various modes of operation were evaluated. The slide shows simulated InSAR phase images of the Wadden Sea for two parameter settings, as obtained from a numerical InSAR imaging model, and (in the top layer depicted in this manuscript) current fields derived from the simulated data, using the same methods that were applied to the SRTM data. According to our findings, the quality of InSAR-derived current fields from TerraSAR-X stripmap data will be superior to the quality of the SRTM results, while the quality of TerraSAR-X ScanSAR data will be somewhat worse. A major improvement of the data quality could be obtained with an antenna extension proposed for TerraSAR-X follow-on projects, which would increase the effective antenna separation and the instrument's sensitivity to small current variations by a factor of 3.

Slide 11



Given the predicted data quality and the limited availability of the experimental along-track InSAR mode, TerraSAR-X cannot be considered as an operational instrument for systematic resource assessment studies for hydropower installations. However, we hope we can demonstrate repeated current measurements from space at a few selected test sites, initiate the development of data synthesis systems for hydrodynamic models, in-situ data, and along-track InSAR data on the basis of TerraSAR-X results, and attract potential users of advanced current data products for collaborations in the development of applications and in the implementation of future spaceborne along-track InSAR missions with improved technical specifications and capabilities. Technical concepts for specific system upgrades for oceanic applications are readily available. This includes antenna and receiver upgrades for a better phase sensitivity and lower instrument noise leading to a better current measuring accuracy and spatial resolution, larger swath widths and an operational availability of along-track InSAR modes for an improved spatial and temporal coverage, and system upgrades for dual-beam interferometry that would permit full vector current measurements during single satellite overpasses. Also the existing data processing algorithms can be upgraded to include wave and wind retrievals from InSAR data in order to get an even more comprehensive and consistent picture of the dynamics in the upper ocean and at the ocean-atmosphere interface.

Literature

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