SATELLITE TECHNOLOGY: AN IMPORTANT TOOL TO UNDERSTAND THE DEEP SUBSURFACE

EXAMPLES FROM IN-SAR DATA AND GOCE SATELLITE

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Symposium: **Space for Subsea**

Pushing Technology Limits

Delft 18th May 2016

MAIN MESSAGE

Remote sensing is becoming important for E&P

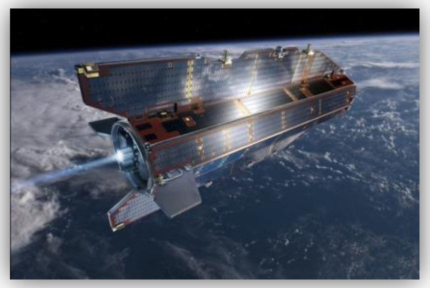
- Applications are not limited to surface imaging and mapping
- It can tell more about deep structures and processes

REMOTE SENSING TECHNOLOGIES FOR E&P APPLICATIONS

- **Two technologies**

1. Interferometric Synthetic Aperture Radar **(InSAR)**
   - **Monitoring of Surface movement for Reservoir characterization**

2. Gravity Field and Steady-State Ocean Circulation Explorer **(GOCE)**
   - **Mapping deep crustal structres from Exploration**



NEW INITIATIVES

- Joint Innovation Center for Interaction Robotics

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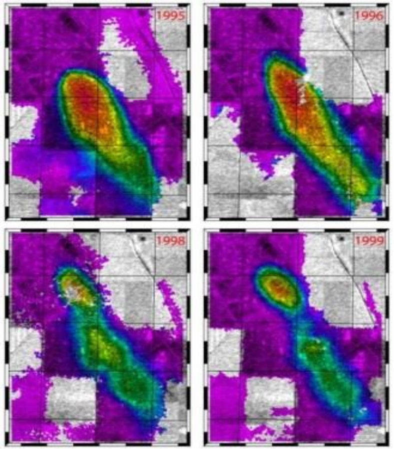
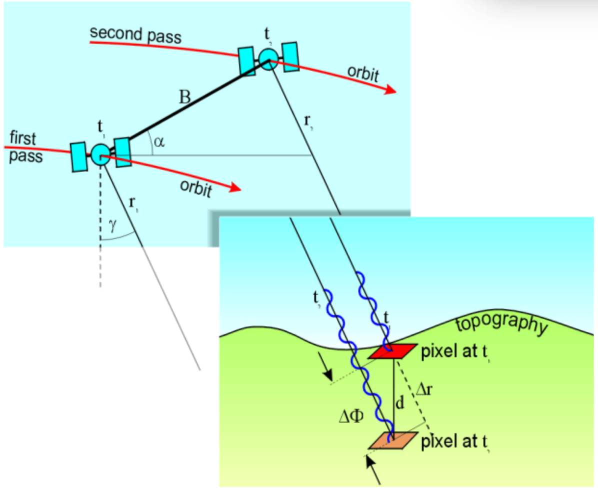
1 INTERFEROMETRIC SYNTHETIC APERTURE RADAR

IN-SAR

- An active remote sensing technique that measures surface deformation in a centimetre to millimetre scale over timespans of days.
- It compares at least two (synthetic aperture radar) images based on differences in the phase of the radar wave.



Rapid ground subsidence over the Lost Hills oil field in California. (NASA/JPL-Caltech)



http://wikipedia.org/Interferometric_synthetic_aperture_radar

IN-SAR FOR FIELD AND RESERVOIR MONITORING

› Surface subsidence observations are linked to subsurface reservoir dynamics

- **Persistent Scatterer Interferometry (PSI)**
- Point-by-point analysis: double-differences

>100 images

Frequent update

TIME SERIES INTERFEROMETRY

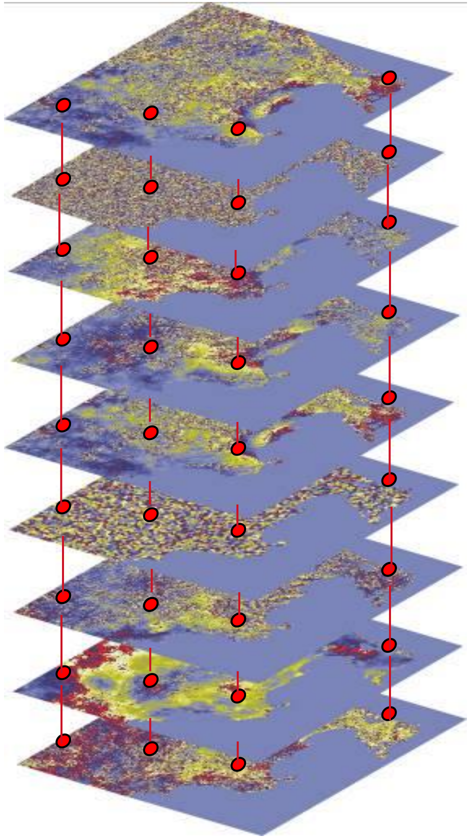


Image F. Serafino, Napels University

IN-SAR FOR FIELD AND RESERVOIR MONITORING

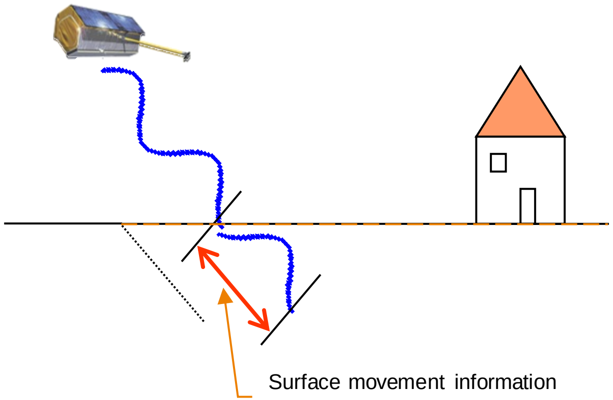
Applications:

1. Hazard assessment due to gas production

2. Observing evolution of pressure plume in the reservoir due to gas (or CO_2) storage

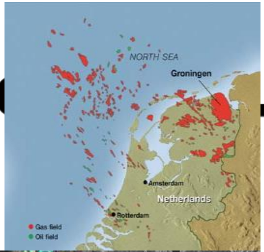
3. Understanding reservoir architecture:

   - Gas-Water contact
   - Aquifer activity
   - Compartmentalization



Examples

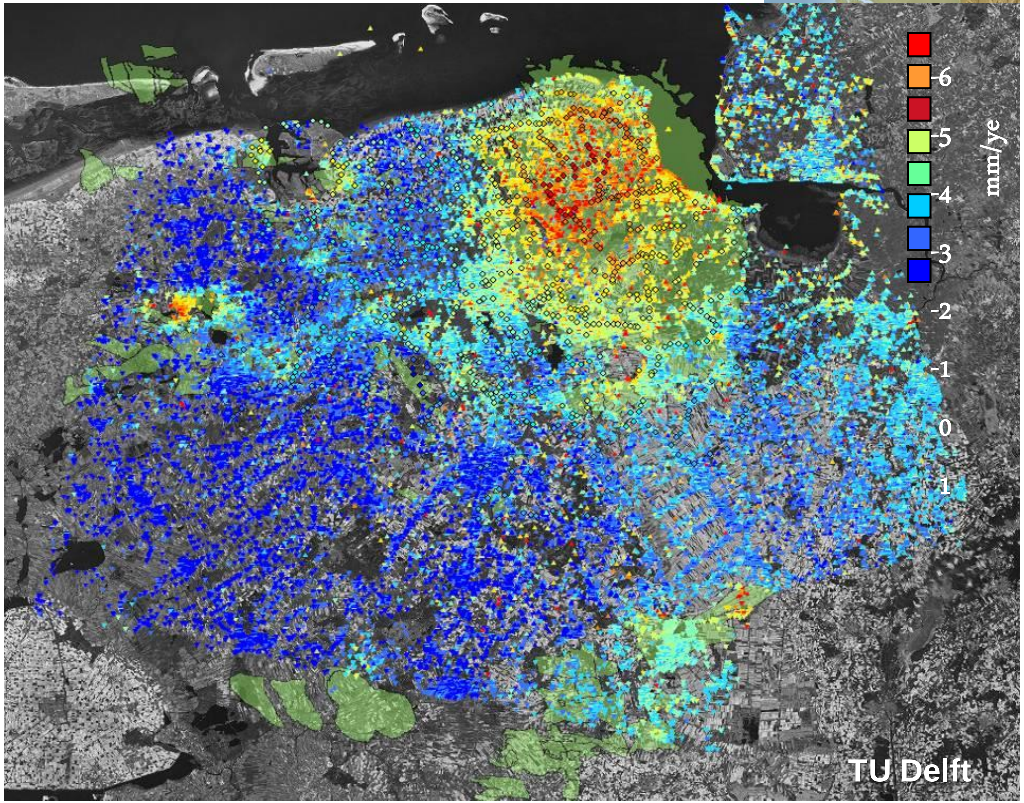
EXAMPLE: GRONINGEN FIELD



Ground Subsidence due to gas production

COMPACTION AND SUBSIDENCE

- Subsidence in NE Netherlands due to gas production (Groningen) and salt mining
- Observed with radar interferometry from satellites (~ 20 years)



EXAMPLE: KRECHBA FIELD, ALGERIA

Monitoring of Underground CO2 Storage

- Underground storage component of Carbon Capture and Storage (CCS) requests strong monitoring plan
- InSAR for monitoring pressure spatial and temporal plume development related to CO2 injection (~ 3 years)

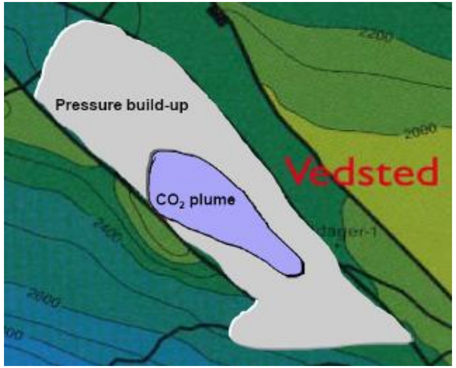
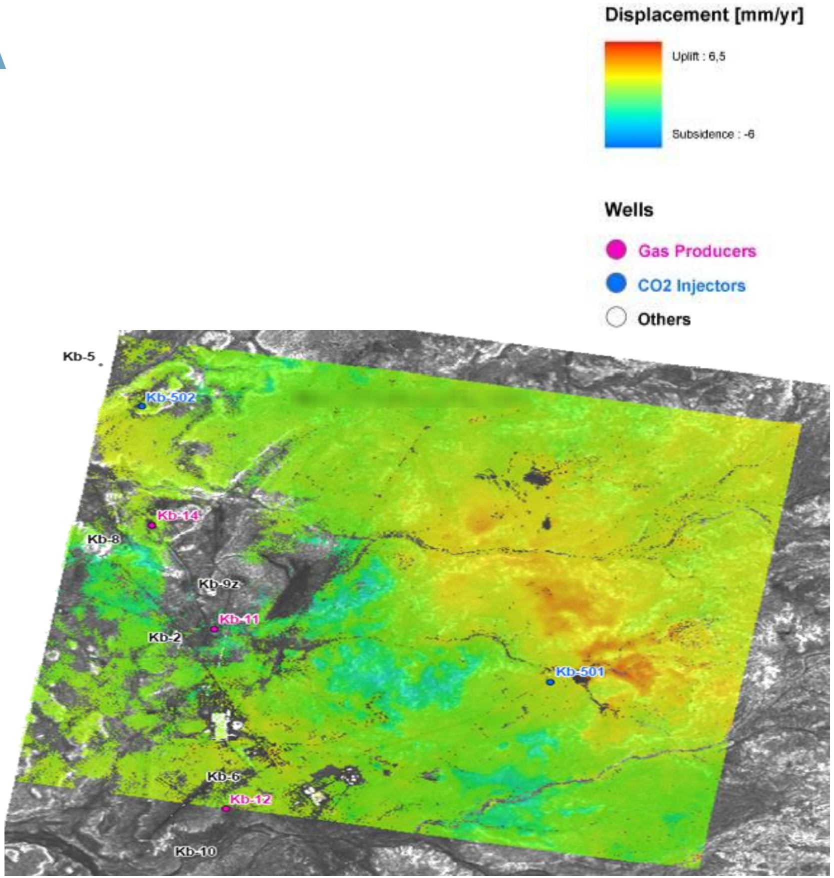


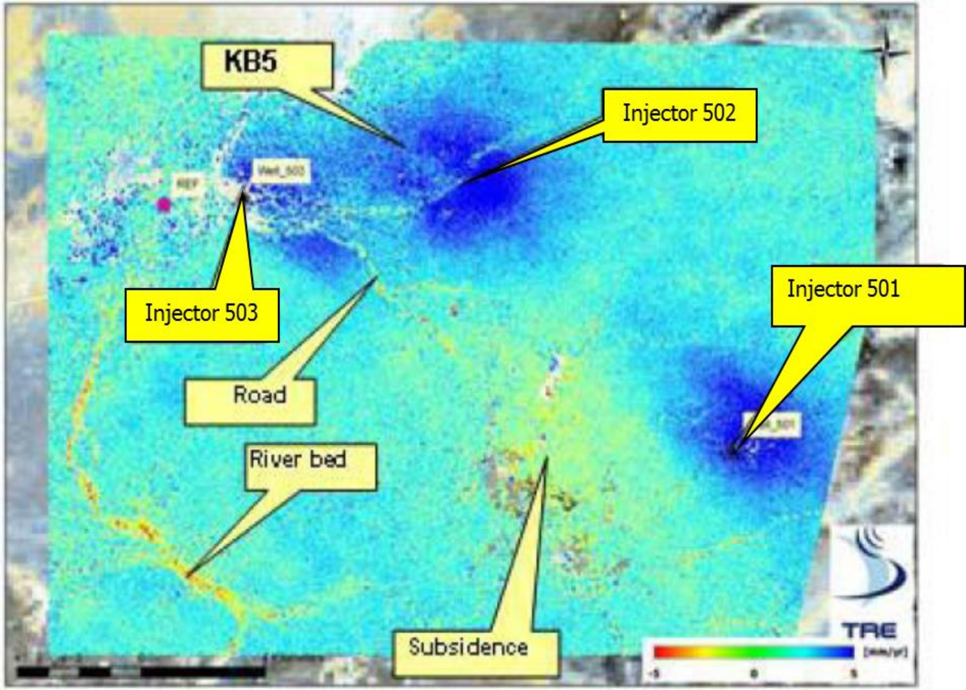
Illustration of CO2 and Pressure Plume Relation [Christensen, 2010]



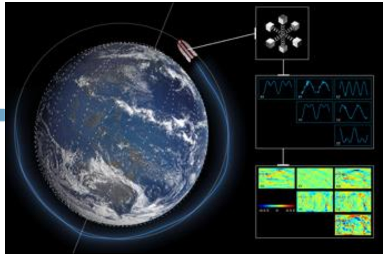
EXAMPLE: KRECHBA FIELD, ALGERIA

Monitoring of Underground CO2 Storage

- CO_2 Injection in the flanks of a gas reservoir
- Surface heave above the injection area
- Surface subsidence above producing area
- CO_2 can be traced in the preferred fault direction



2 THE GOCE SATELLITE GRAVITY MISSION



The GOCE satellite gravity mission

- Gravity Field and Steady-State Ocean Circulation Explorer **(GOCE)**
- ESA satellite launched in 2009 and mission
- Measures gravity gradient (gradiometer)
- Objectives:
  - Gravity field with high accuracy
  - Determine the Geoid (1-2 cm)
  - Spatial resolution of ~ 75 km

Application	**Accuracy, Geoid** [cm]	**Accuracy, Gravity** [mGal]	**Spatial Resolution** (half wavelength) [km]
Solid Earth			
Lithosphere and upper-mantle density structure		1-2	100
Continental lithosphere:			
• sedimentary basins		1-2	50-100
• rifts		1-2	20-100
• tectonic motions		1-2	100-500
• Seismic hazards		1	100
Ocean lithosphere and interaction with asthenosphere		0.5-1	100-200

- GOCE data: suitable resolution for the regional scale studies
- Suitable for crust and lithosphere studies (crust thickness)
- Gradient data: higher horizontal resolution for crustal structure (densities) discrimination.
- GOCE data can help constraining he crustal thickness; essential for heat flow modeling

GOCE SATELLITE GRAVITY DATA IN GEOPHYSICAL EXPLORATION AND BASIN MODELING

Case study from the Rub’Al-Khali basin (Arabian Peninsula)

esa

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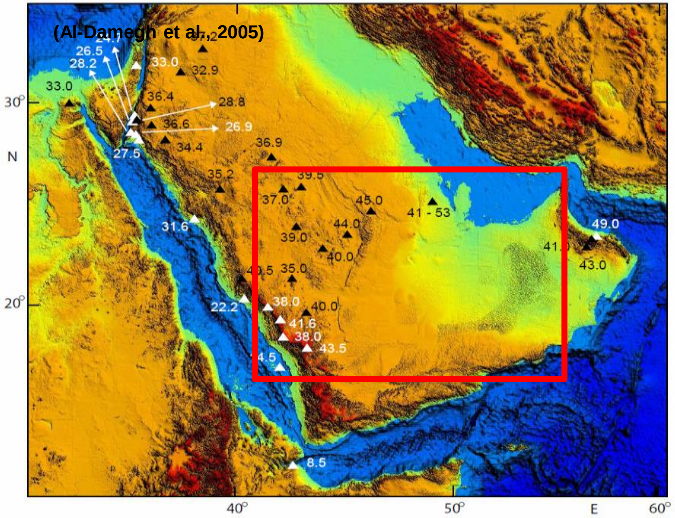
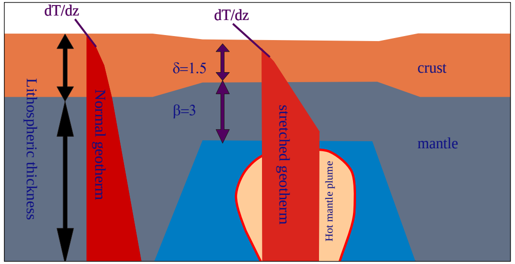
NGU Geology for Society since 1858



Modelling tectonic heat flow



Calibratio
n

GOCE Gravity Gradient

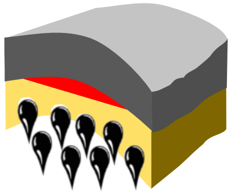
Update Crustal Model

3D Heat Flow model

Maturity of source rocks

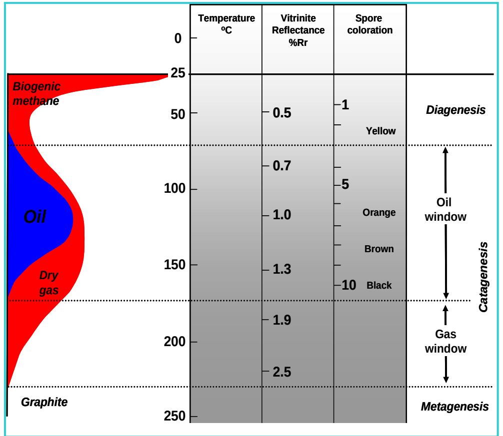
Calibratio
n

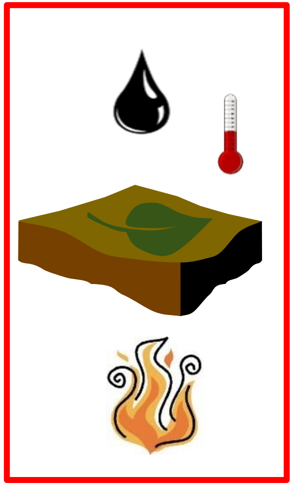
THERMAL STRUCTURES AND HYDROCARBON GENERATION



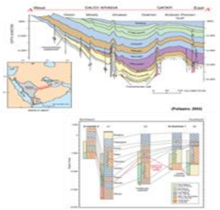
Heat flow in the basin

- The amount of heat within the basin controls the maturity of the source rocks.
- It is generally identified by the heat flow [mW/m-2] in the basin.
- Heat flow can vary through geological times

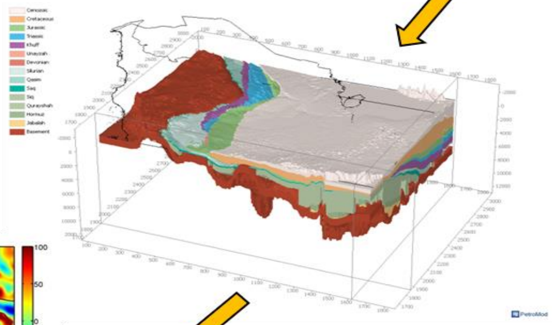


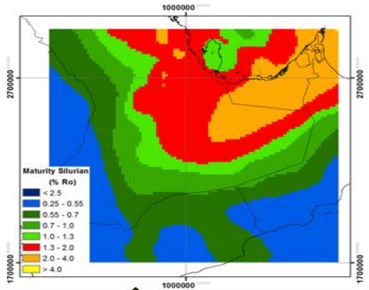


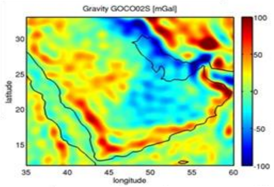
GOCE: Case study from the Rub’Al-Khali basin (Arabian Peninsula)

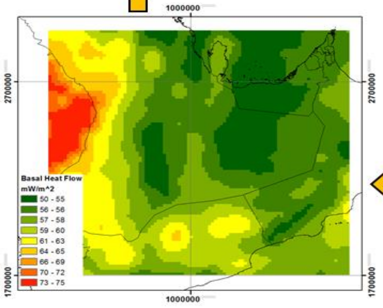


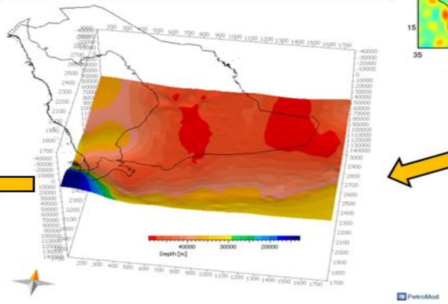
Workflow

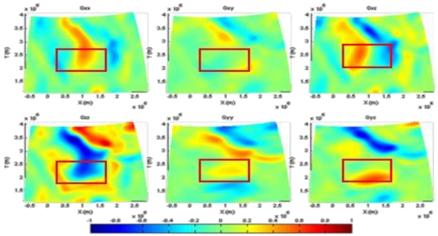


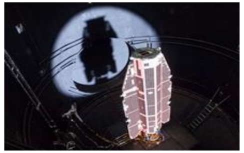






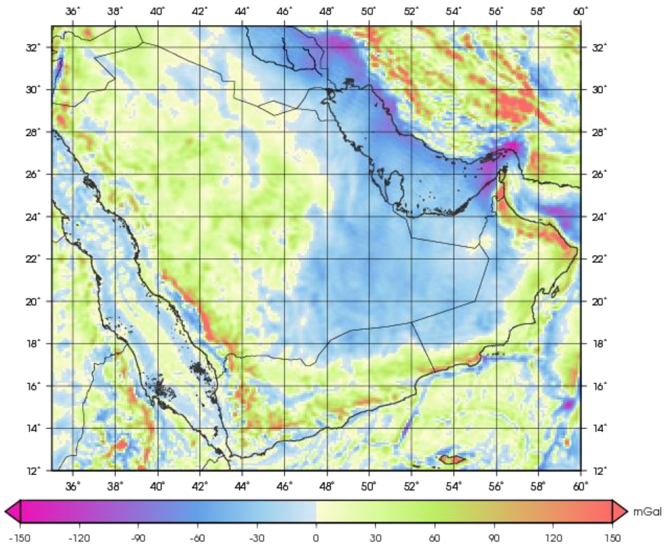




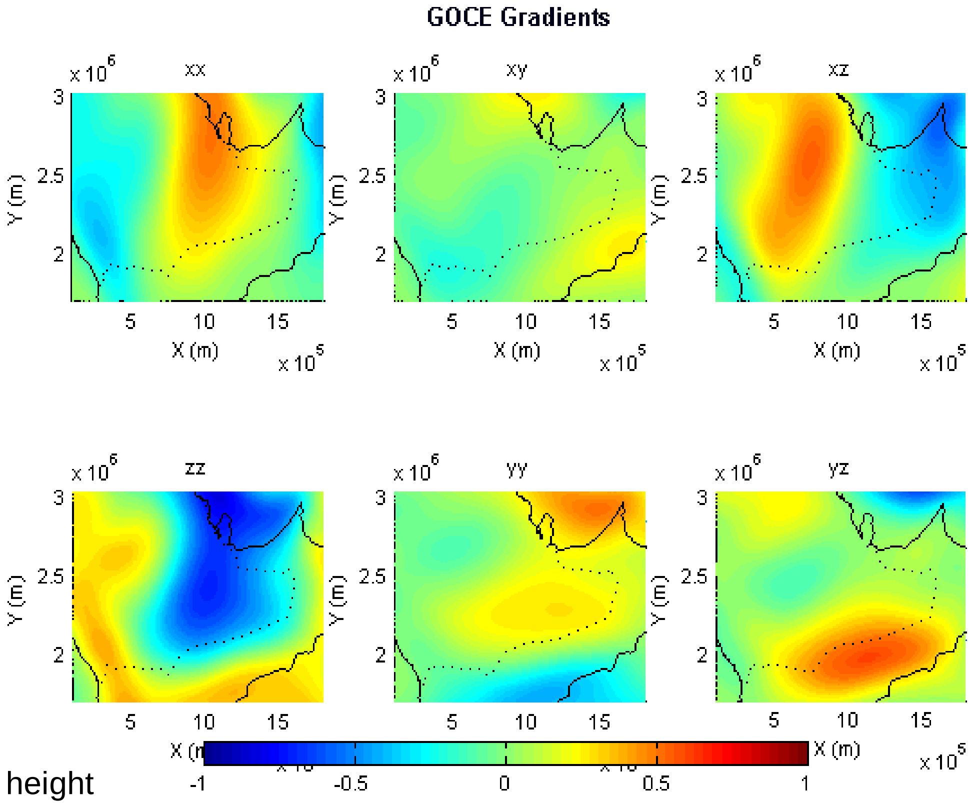


INPUT DATA: GOGE-BASED CRUSTAL MODEL

GOCE Data over Rub' Al-Khali



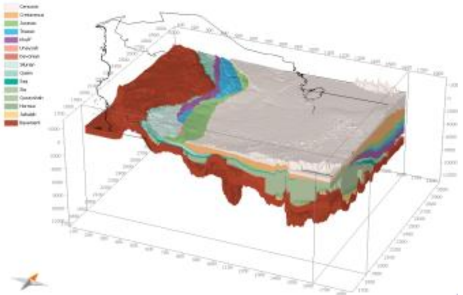
Free-Air gravity (EIGEN-6C)

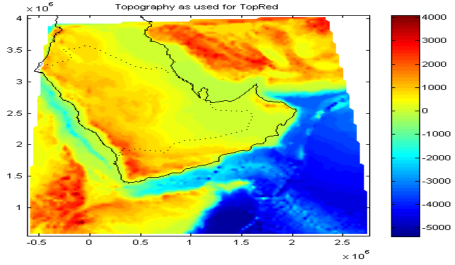


Gravity gradients at orbital height (260 km) for the Arabian Peninsula

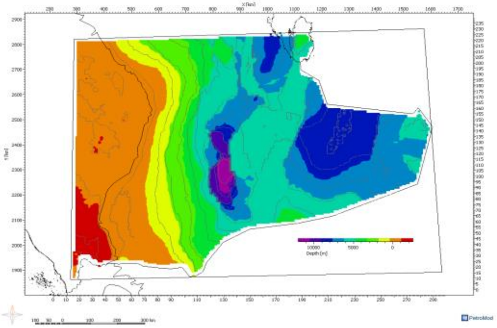
INPUT DATA: GOGE-BASED CRUSTAL MODEL

GOCE Data Interpretation Workflow

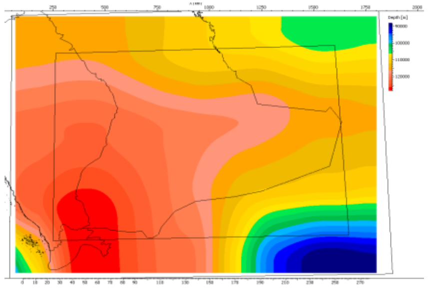




Topography: ETOPO1



Top Basement (Konert et al., 2001)



Base Lithosphere: (Artemieva 2007)

GOCE gradients

↓

Topography mass correction

↓

Subtract contribution Top Basement

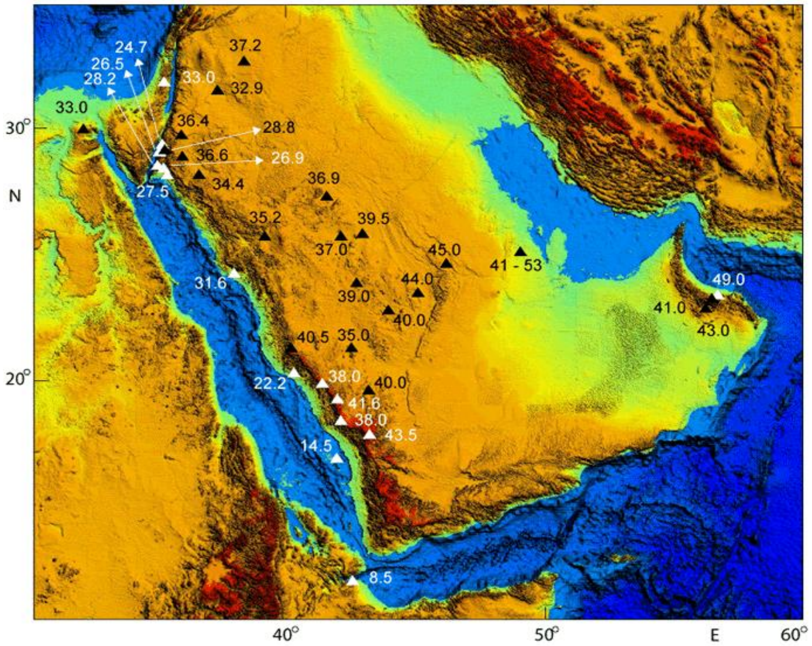
↓

Subtract contribution Upper Mantle

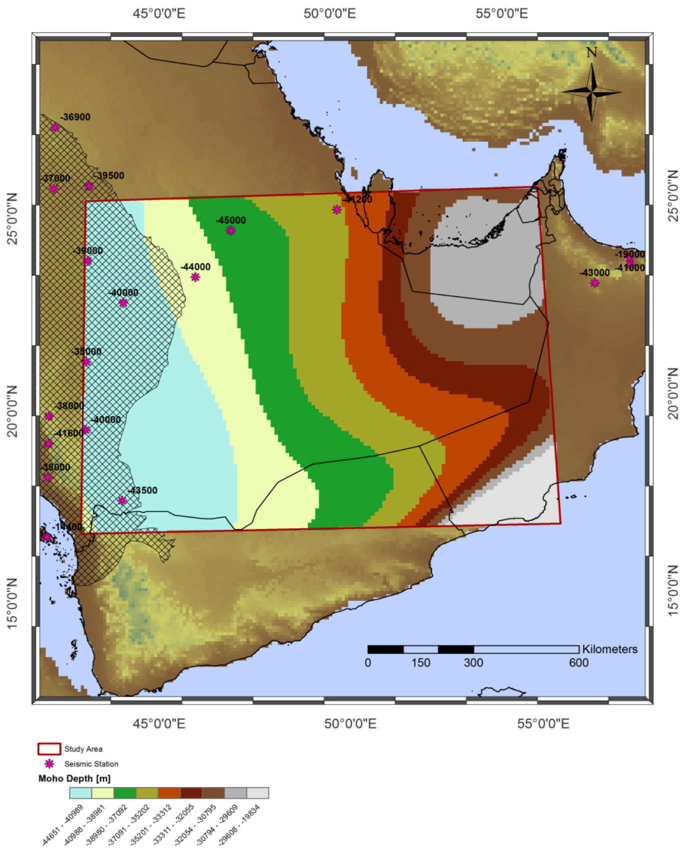
↓

Invert residual to Moho

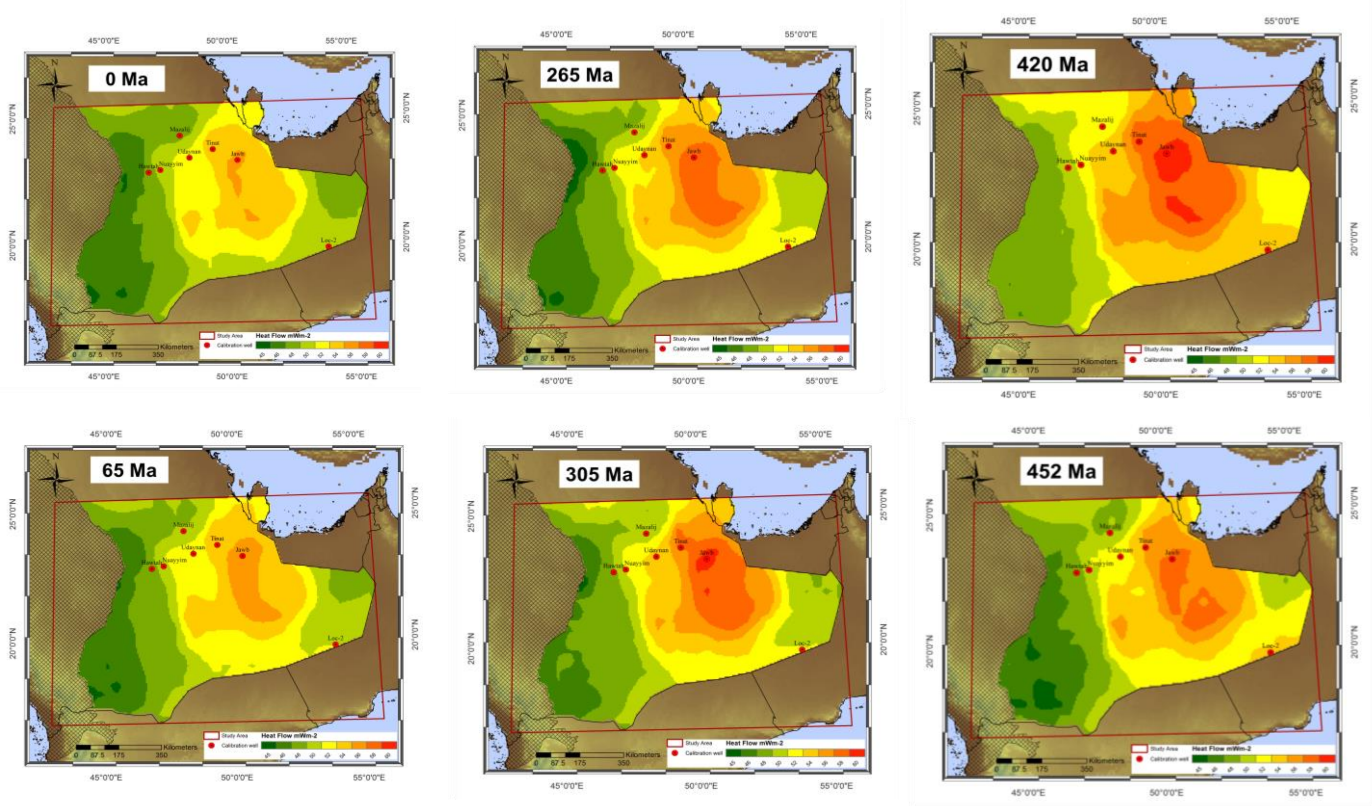
GOGE-BASED CRUSTAL MODEL



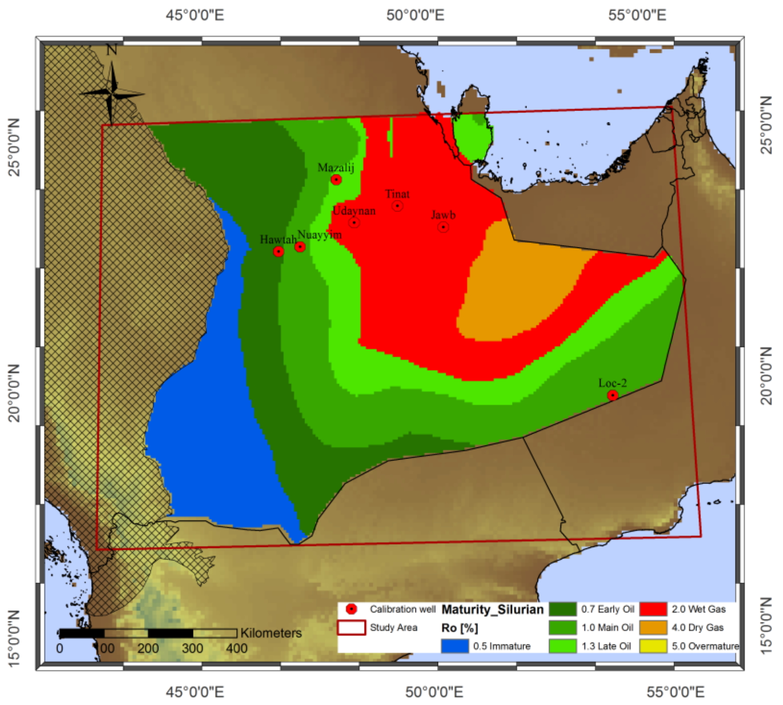
(Al-Damegh et al. 2005)



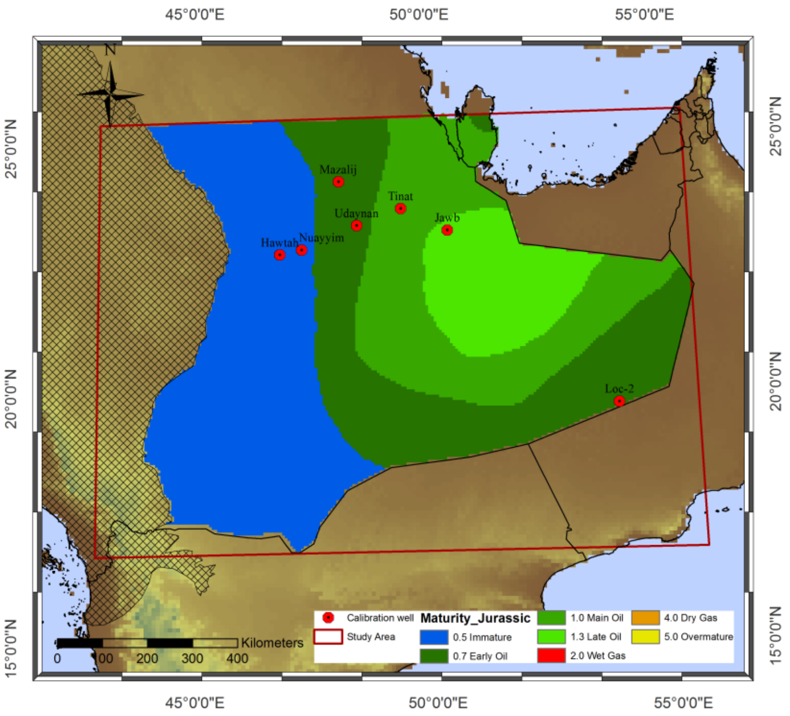
RESULTS: MODELED TECTONIC HEAT FLOW



RESULTS: MATURITY OF THE SOURCE ROCKS

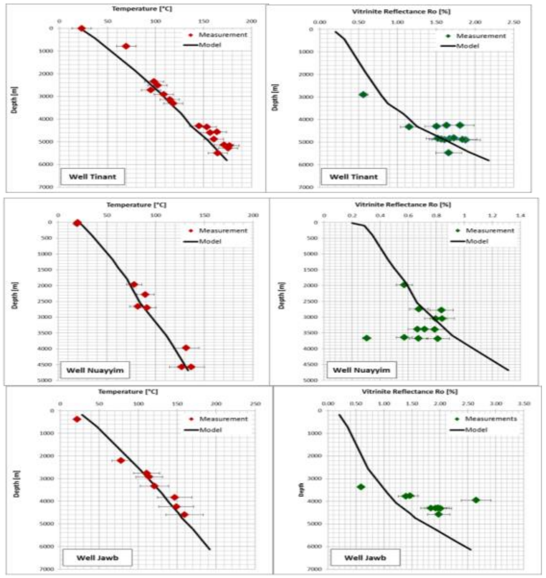


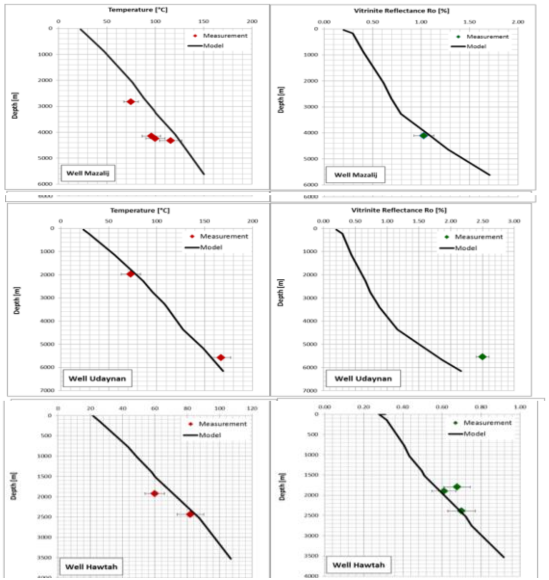
Top Silurian SR

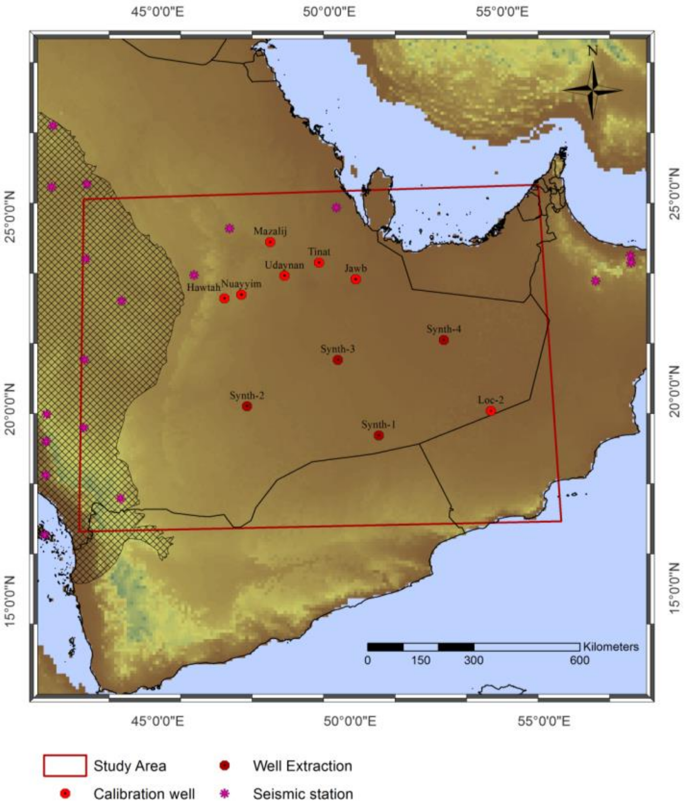


Top Jurassic SR

RESULTS: CALIBRATION OF THE RESULTS







Abu-Ali and Littke, (2005). Abu-Ali et al., (1999) Milner, (1998)

GOCE: CASE STUDY FROM THE RUB'AL-KHALI BASIN (ARABIAN PENINSULA)

Conclusions

- Careful interpretation of the GOCE GG data can help in mapping deep structures
- A new crustal model based on the inversion of gravity gradient data from GOCE satellite
- We modeled heat flow over the whole basin and throughout the geological history of the basin
- Based on this the hydrocarbon maturity of the source rocks were estimated in the remote Rub Al Khail Basin.

Advanced Satellite technology for E&P activities Summary

- *Remote sensing is becoming important for E&P applications*
- *Larger areal and temporal coverage*

- *Satellite-based subsidence measurements (PS – InSAR) can be used for:*
  - Pressure and plume evolution in the reservoir
  - Identification of gas-water contact
  - Improve our reservoir models and predictions
  - Applicable for IOR, natural gas and CO_2 storage, hazard monitoring

- *GOCE gradient data is a promising tool for mapping deep crustal structures*
  - In combination with heat flow models it can have important applications for exploration
  - Support exploration activities in remote area and frontier basins (**Arctic region, deep ocean basins**)

- Complementary to other techniques
- Integrated Workflow is required
- More case studies are required

3

NEW INITIATIVE

Joint Innovation Center for Interaction Robotics

- Developing Robotic Innovations for Enhancing Robotic Capabilities

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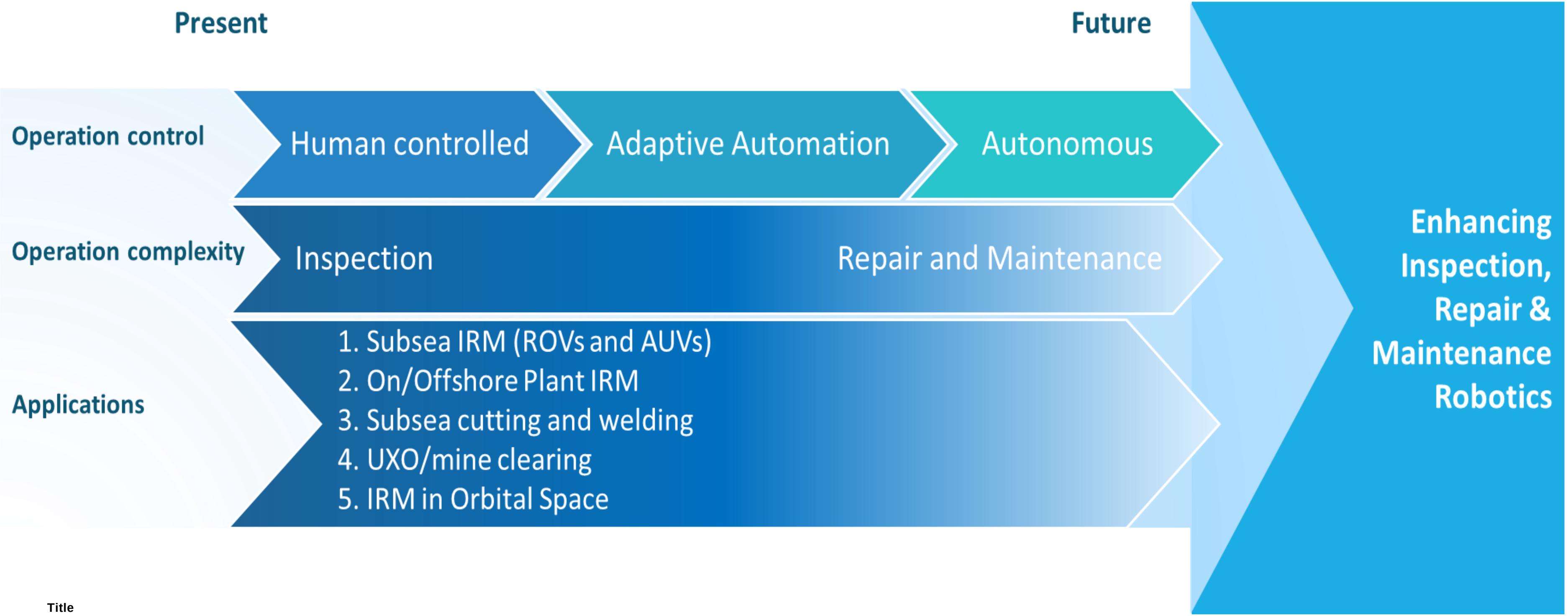
TELE OPERATED ROBOTIC INSPECTION, REPAIR & MAINTENANCE:



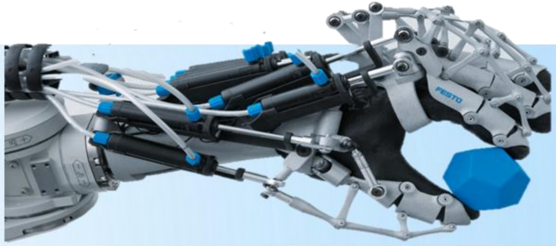
JIC FOR ENHANCING ROBOTIC CAPABILITIES

PROGRAM LINES 1 & 2

Subsea
Surface
Space

1. Enhancing Inspection, Repair & Maintenance Robotics

Indoor
Outdoor
Harsh environments



2. Easy-to-wear, active Exoskeletons For Human Enhancement

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THE VALUE CHAIN

Component Suppliers → Robot/ROV OEMs → Service Providers → End Users

Potential Stakeholders

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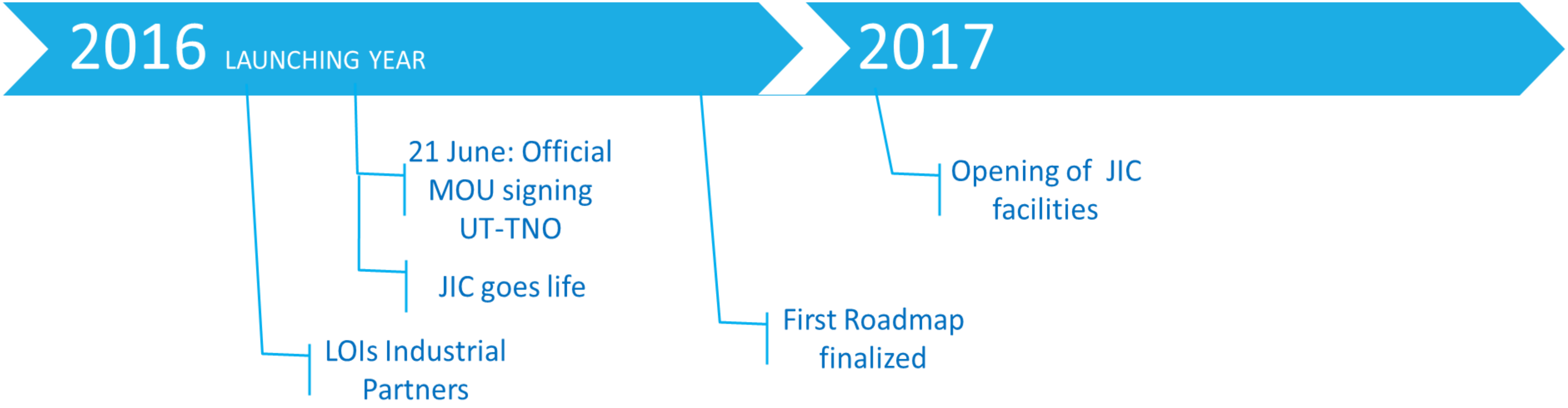
TIMELINE



LAUNCHING YEAR OBJECTIVES:
Develop Roadmap with Key Stakeholders, start first Business case and Open/define the New JIC Facilities in the Netherlands

JOINT INNOVATION CENTER FOR INTERACTION ROBOTICS

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TO CONCLUDE WITH

1. Interferometric Synthetic Aperture Radar **(InSAR)**
   - ❑ **Monitoring of Surface movement for Reservoir characterization**

2. Gravity Field and Steady-State Ocean Circulation Explorer **(GOCE)**
   - ❑ **Mapping deep crustal structres from Exploration**

3. Joint Innovation Center for Interaction Robotics

THANK YOU FOR YOUR KIND ATTENTION

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