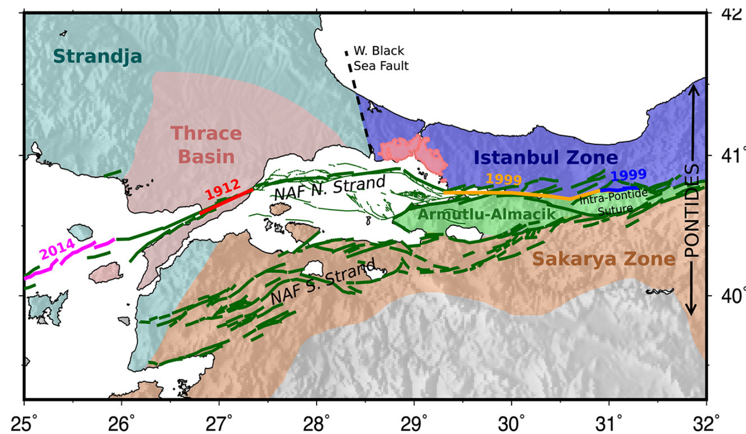
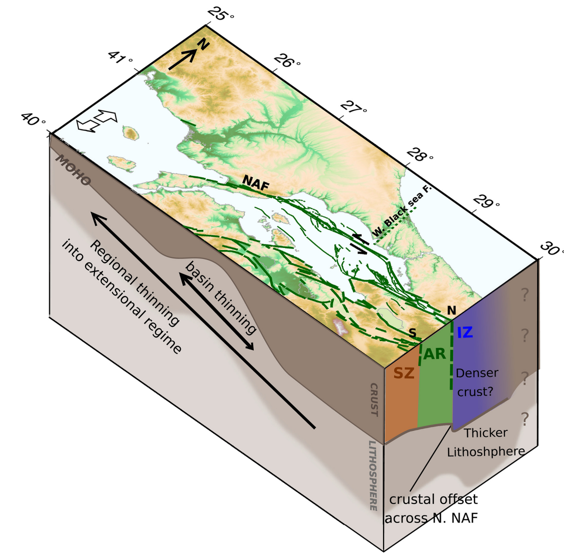
Crustal Thickness Variation Across the Sea of Marmara Region, NW Turkey:

A Reflection of Modern and Ancient Tectonic Processes





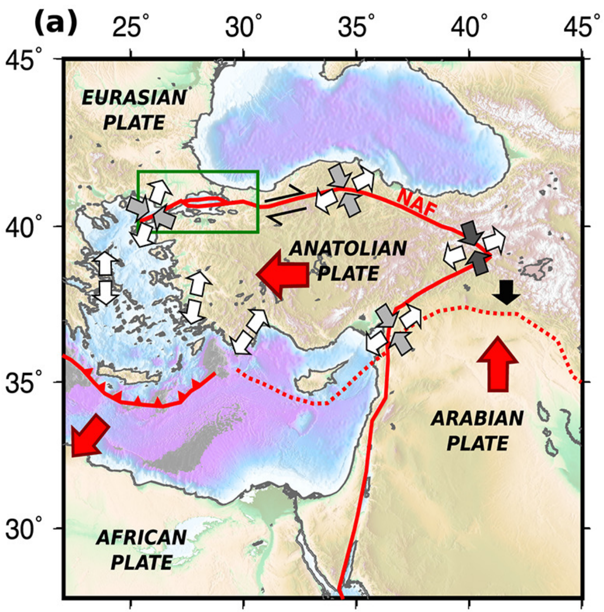
Jenny Jenkins, Simon Stephenson, Pati Martinez-Garzon, Marco Bohnhoff & Murat Nurlu

Setting: Sea of Marmara region – NW Turkey

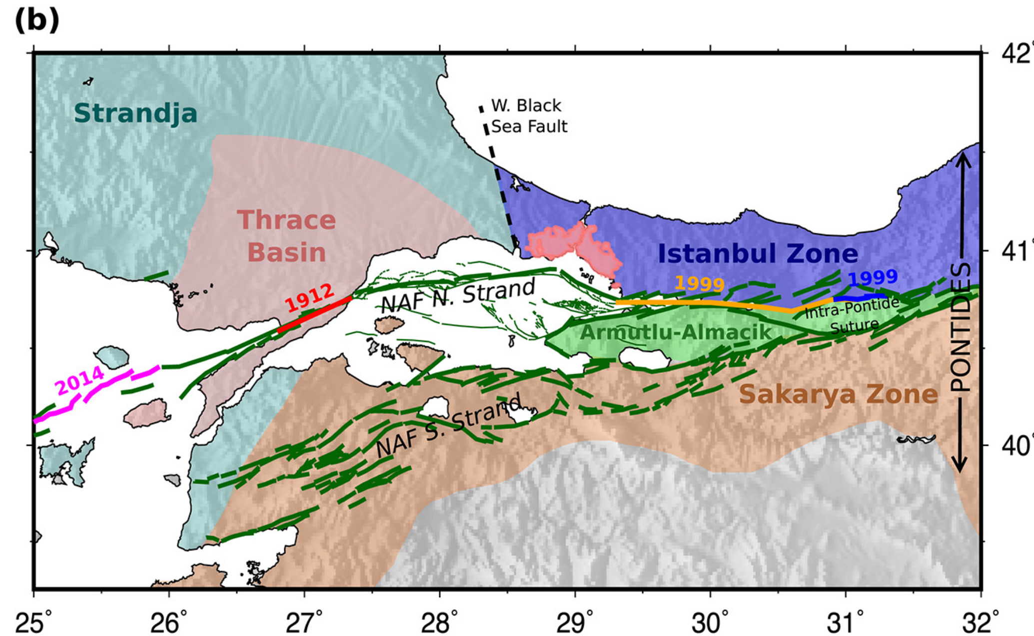
Present Day Tectonics:
- N-S extension driven by Hellenic slab roll back
- Bisected by E-W strike-slip North Anatolian Fault
- Transtensional Sea of Marmara basin

Ancient Crustal Terranes:

Made up of an accumulation of island arc/continental domains brought together by the closure of the Tethys Ocean separating Laurussia and Gondwana.



Adapted from Facenna et al., (2006)



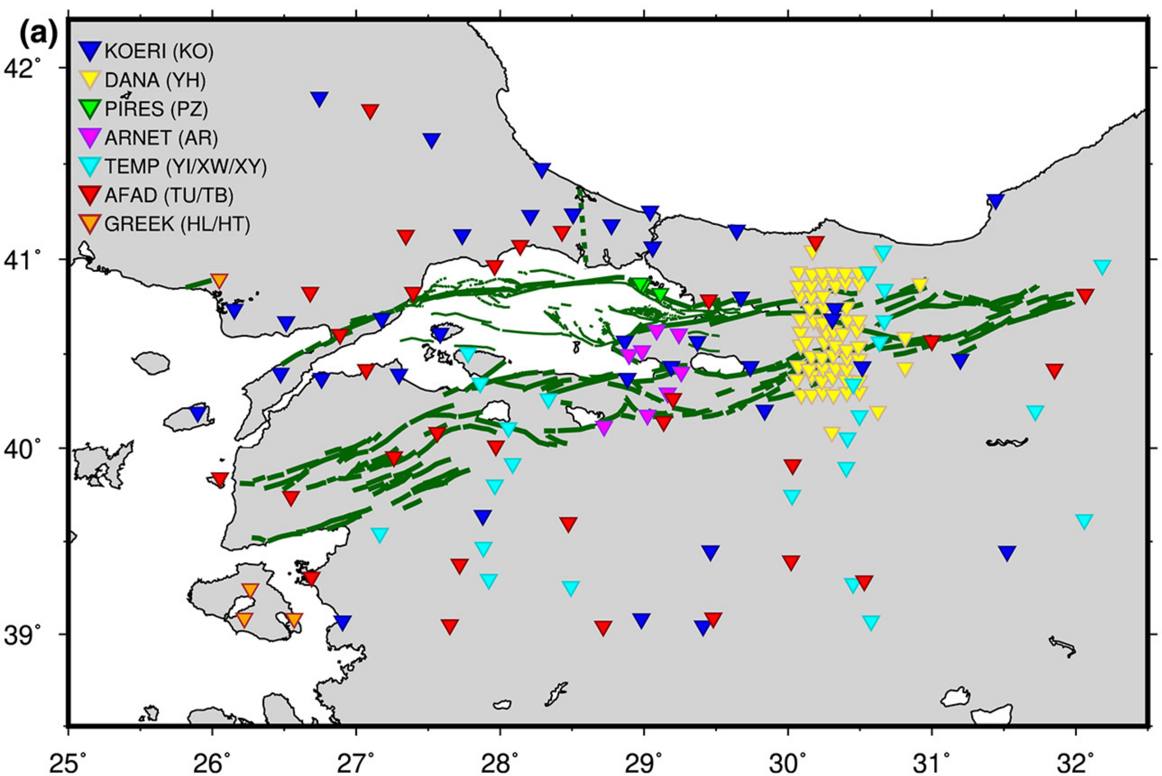
Question:

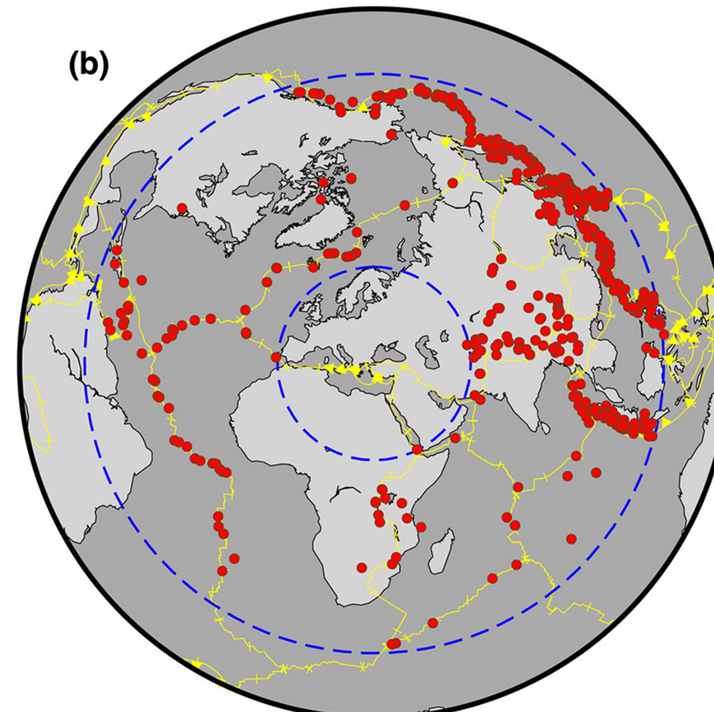
How do active tectonics and ancient terranes interact to shape modern day crustal structure?

Data: Seismic stations and earthquakes

174 broadband seismic stations:
All publicly available data plus data from national monitoring AFAD network and temporary networks on princes islands and the Armutlu peninsular

Teleseismic earthquakes:
Large magnitude (Mw 5.5-8.5) events at 30-90 epicentral degrees distance from recording stations

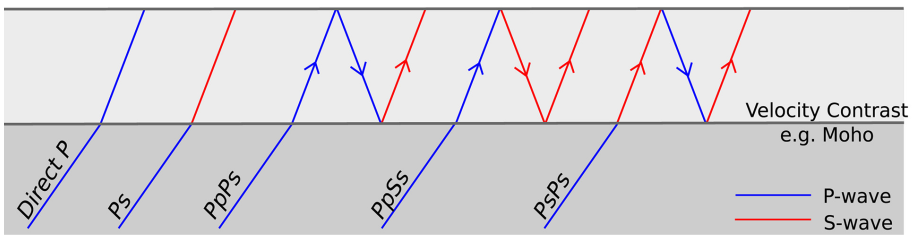


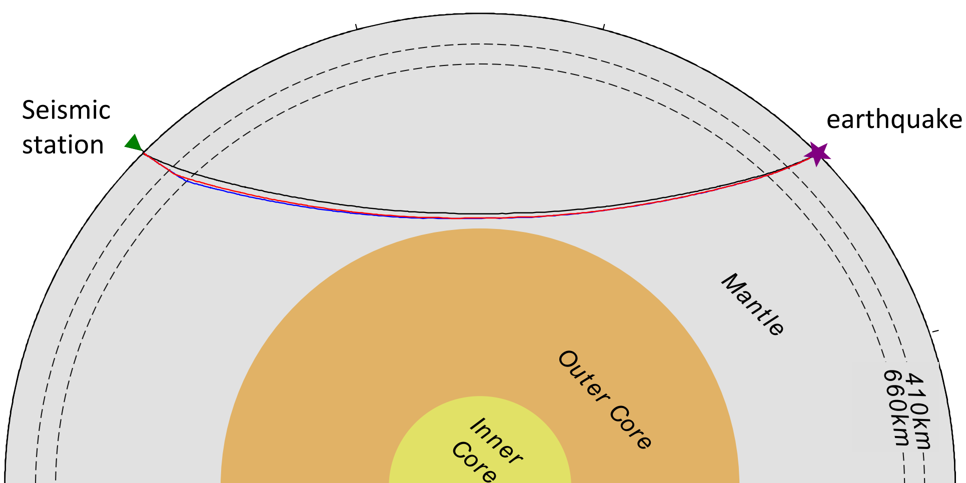


Method: Receiver functions and P-s conversions

P-s Conversions:

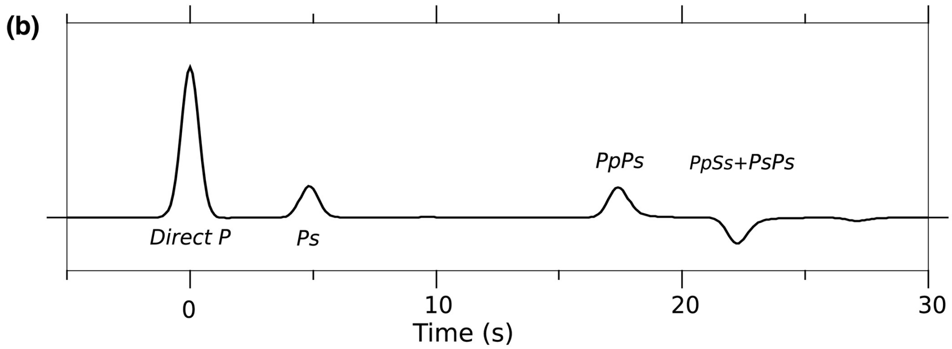
When P waves hit a sharp boundary (e.g. the Moho) they can be converted to S waves. These P-s conversions, and multiples that bounce within the layer, can provide information on the depth of the converting boundary.





Receiver functions:

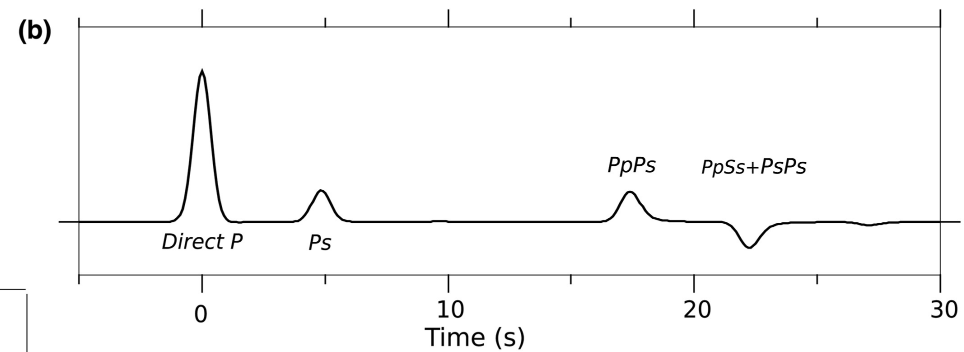
Deconvolving the vertical from the radial component of ground motion produces a receiver function (RF), example shown below, which emphasise P-s converted phases and multiples

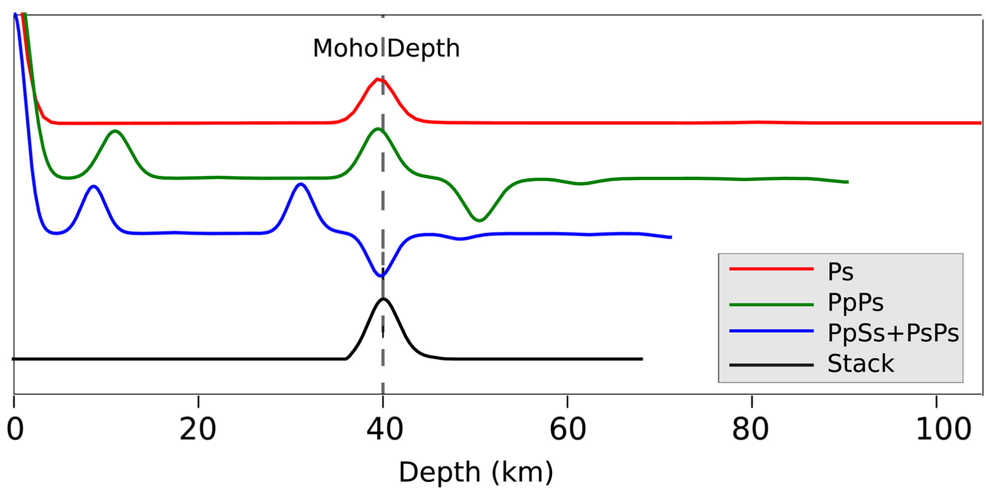


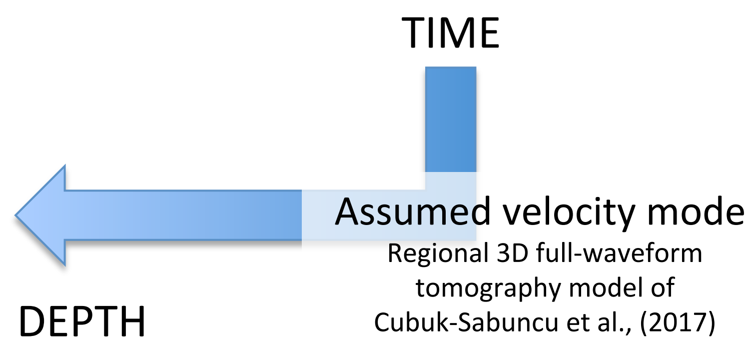
Method: Multi-phase RF time-depth conversion

Time to depth Conversion:
RFs can be converted from a time series to depth series where arrivals show depths of the causitive seismic boundary (e.g. Moho), by assuming a known velocity structure.

Time to depth conversions assume a specific phase – so other phase arrivals will be mapped to incorrect depths. 3 different time to depth conversions, assuming 3 different phases (Ps arrival and two multiples), can be combined into a single trace where all arrivals appear at a common depth. This is called multi-phase stacking and has the advantage that multiples will not be mis-interpreted as representing real structure.



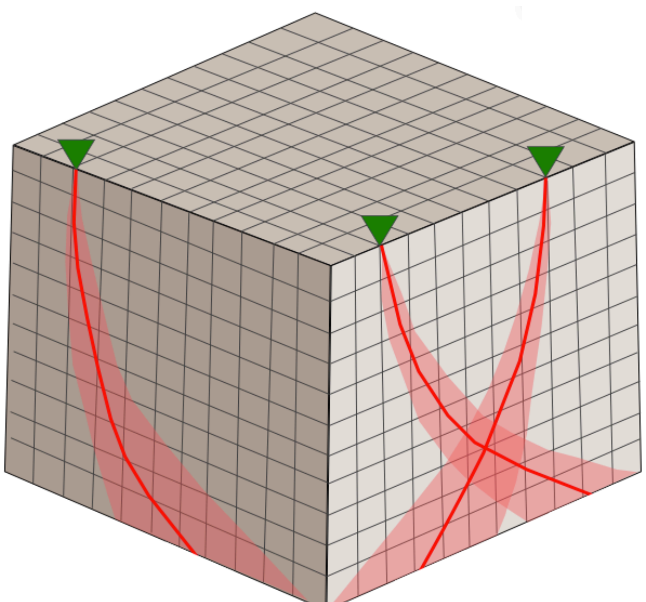




Method: Common conversion point (CCP) stacking

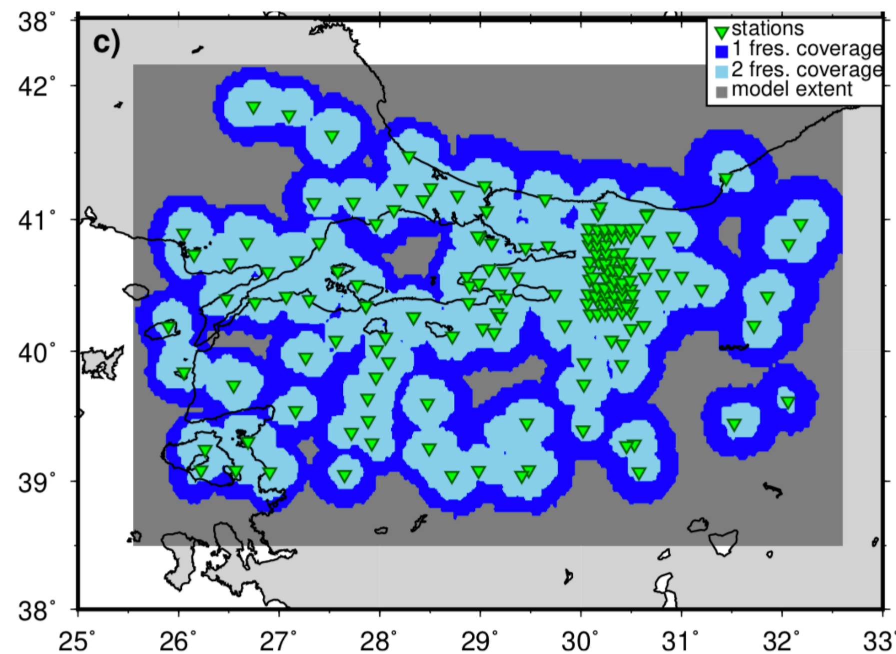
CCP Stacks:

Earthquake rays do not sample directly beneath recording stations but along curved raypaths, sensitive to structure within the area around the raypath (fresnel zone). We back-project data along raypaths into a 3D grid of the Marmara region and stack data that sample the same location at depth – this technique is known as common conversion point (CCP) stacking.



Data smoothing:

Data can be smoothed by adding it across more than the fresnel zone region of sensitivity. We produce a smoothed regional Moho map (data added across 2 frenel zone) and a higher-resolution map (data added across 1 fresnel zone) to the east of the Sea of Marmara where there is greatest data coverage – shown below.



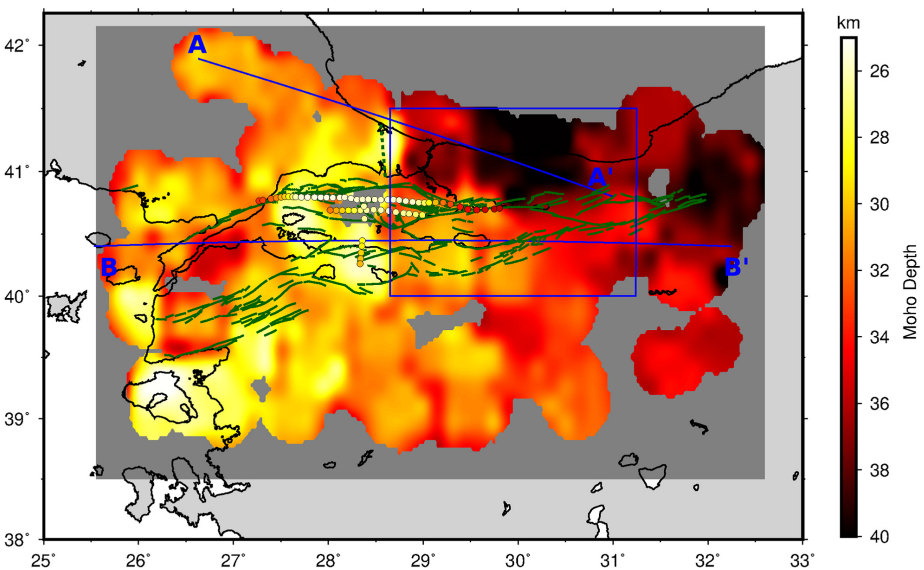
Results: Regional Moho map (smoothed)

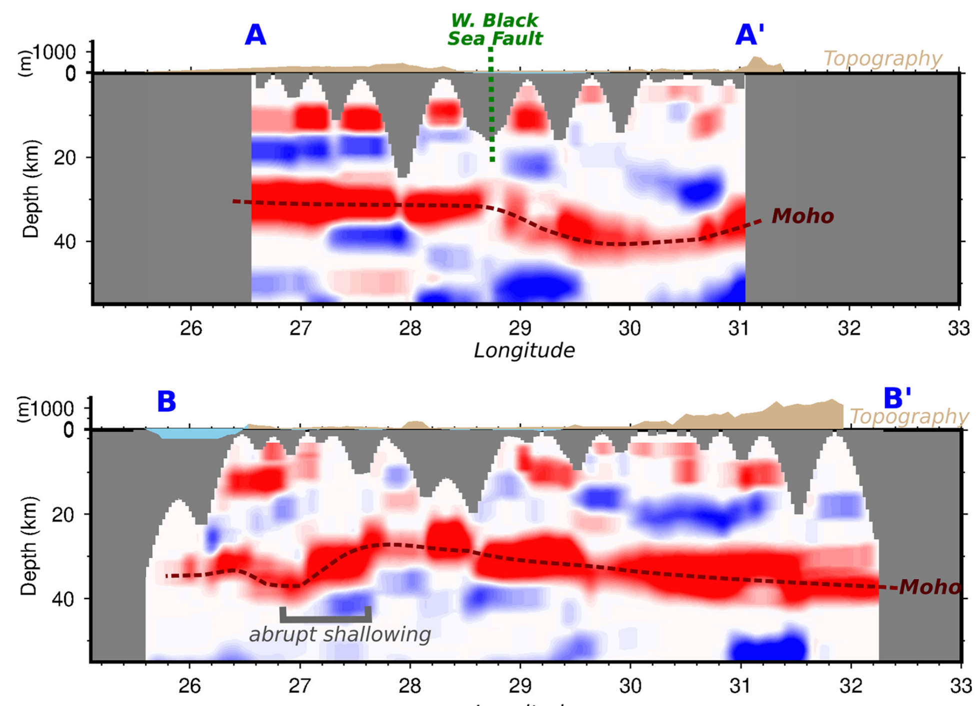
Regional observations :

- General westwards thinning of crust
- Thinnest crust within western Sea of Marmara Basin
- Abrupt Moho depth increases at W. Black Sea fault and across N. branch of North Anatolian fault east of Sea of Marmara - concident with the edges of the Istanbul Zone crustal block

Interpretation:

- Increasing extensional affects moving westwards
- Transtentional basin opening thins crust
- Istanbul Zone is a distinct terrane of thicker (~40km) crust. The edges of this terrane are exploited by faults





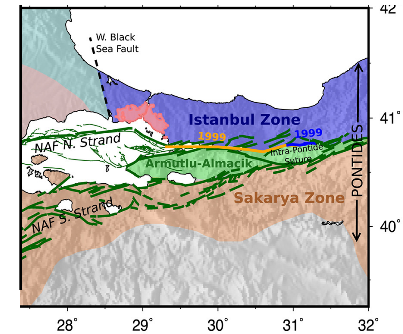
Results: Istanbul Zone

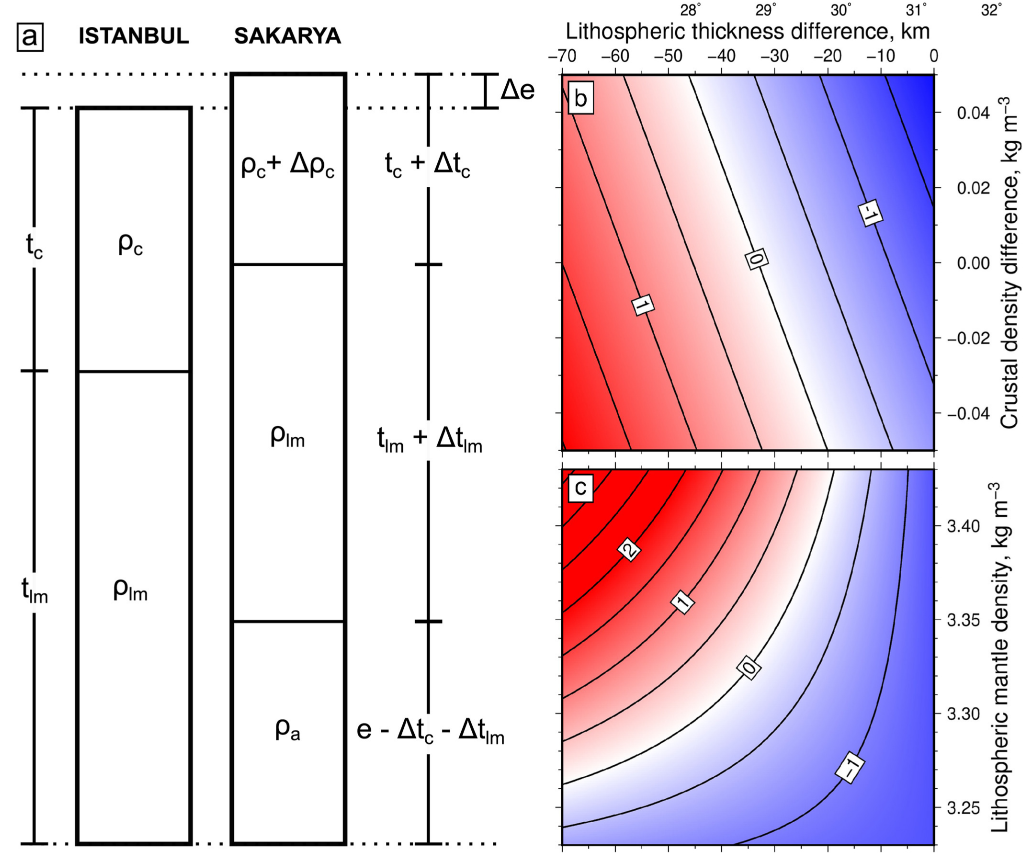
Isostatic Modeling:
We observe the distinct Istanbul Zone crustal terrane has thick crust (~40 km). This region of thick crust shows lower elevations (-0.6 km) than the thinner (-6 km) crust of the Sakarya Zone to the south. Since thicker crust is generally balanced out by higher elevations, this suggests the Istanbul Zone is not in crustal isostatic equilibrium.

Simple isostatic balance models (right) suggest the Istanbul Zone requires thicker lithosphere (+45 km) or greater crustal density (+0.13 kgm^{-3}) compared to the Sakarya zone. Allowing lithospheric density to vary (for fixed crustal density) still suggests thicker lithosphere (~20 km) is required beneath the Istanbul Zone.

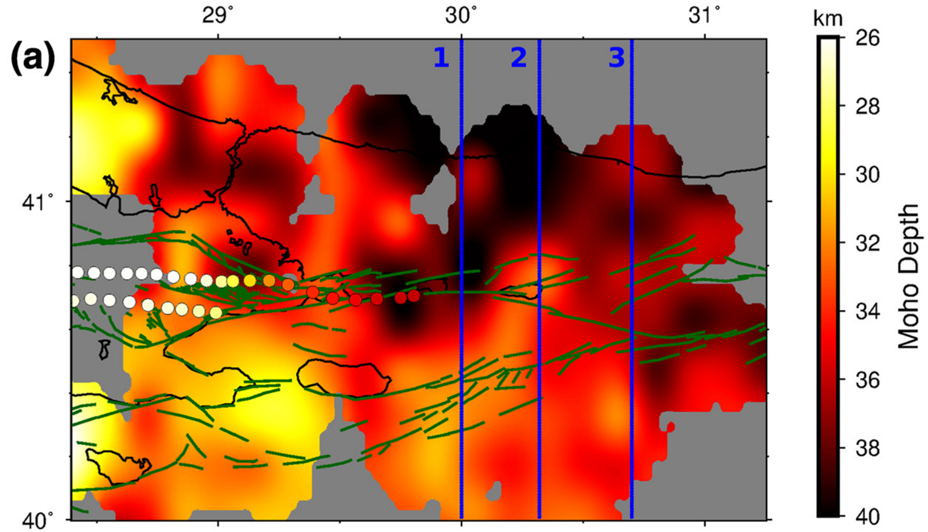
Interpretation:
The Istanbul Zone is likely to have lithosphere 10s of km thicker than surrounding areas, consistent with it's hypothesised origin north of the Black Sea on the Odessa Shelf.

$$\Delta e=\Delta t_c\left(\frac{\rho_a-\rho_c}{\rho_a}\right)+\Delta t_{lm}\left(\frac{\rho_a-\rho_{lm}}{\rho_a}\right)-(t_c+\Delta t_c)\left(\frac{\Delta\rho_c}{\rho_a}\right)$$





Results: Moho map (higher-resolution)

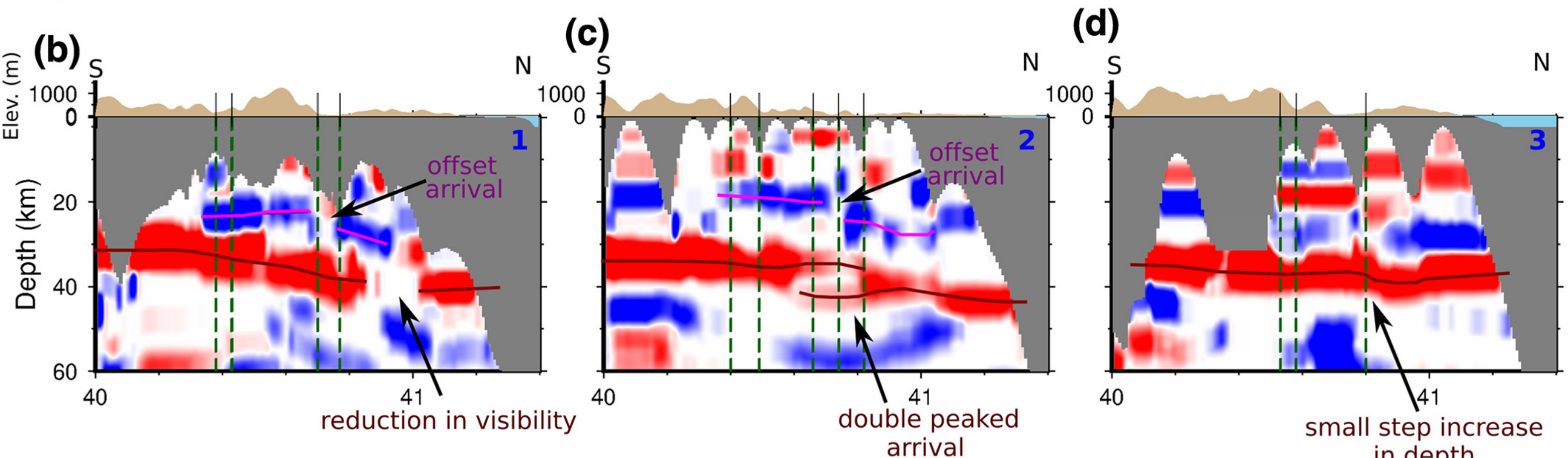


Detailed observations across fault zones:

- Offset arrivals and increased complexity of arrivals across northern branch of North Anatolian Fault down to 40 km
- Little suggestion of offset arrivals across southern branch

Interpretation:

The northern branch of the North Anatolian Fault extends down to Moho depths, while the southern branch is likely limited to shallower depths. These observations are consistent with greater slip accomodation on the northern branch.

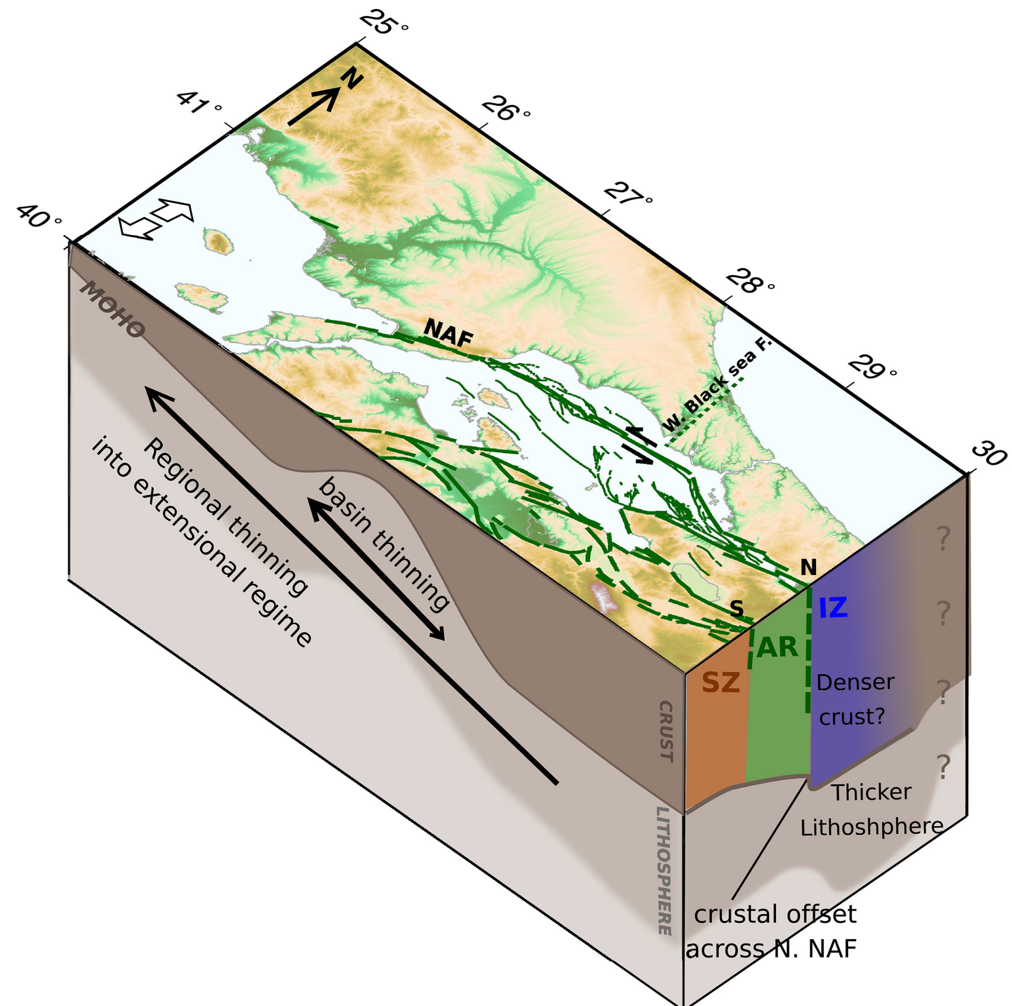


Interpretation: A reflection of modern & ancient tectonics

Conclusions:

Crustal structure in the Marmara region is complex, influenced by ongoing tectonic processes and the ancient crustal blocks that make it up.

- General trends of westward crustal thinning are seen due to trench rollback-driven extension in western Anatolia
- Thinnest crust (26 km) is seen in the western Sea of Marmara, reflecting transtensional basin opening
- A region of increased crustal thickness (~40 km), with sharp boundaries at the northern branch of the North Anatolian Fault and the extinct West Black Sea Fault, represents the crustal terrane of the Istanbul Zone (IZ).
- The IZ's thick crust and low topography suggest it is not in crustal isostatic equilibrium, probably due to loading by thicker lithospheric mantle.
- Disruption of discontinuities across the northern branch of the North Anatolian Fault indicates localized strain extends to depths of at least 20 km if not deeper, but not along the southern branch.



Thanks for your interest!

The 2-minute presentation linked to this work is on: Wednesday, 28 April 2021, 09:17 CEST
In TS4.4 - 'Active Tectonics and Geodynamics of Eastern Mediterranean'

Come and ask questions at the breakout text: Wednesday, 28 April 2021, 09:30-10:30 CEST

For more details see the published paper in AGU:Tectonics

Tectonics

RESEARCH ARTICLE
10.1029/2019TC005986

Key Points:
- We present a new regional map of Moho topography in the Marmara region, based on RF CCP stacks
- Westward crustal thinning reflects the effect of ongoing extension in western Anatolia and the neighbouring Aegean region
- Abrupt changes in crustal thickness define the non-crustally compensated ancient terrane of the Instanbul block

Crustal Thickness Variation Across the Sea of Marmara Region, NW Turkey: A Reflection of Modern and Ancient Tectonic Processes

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Moho maps are provided in the supplementary and free to use

Please feel free to contact lead author Jenny Jenkins if you have any questions:
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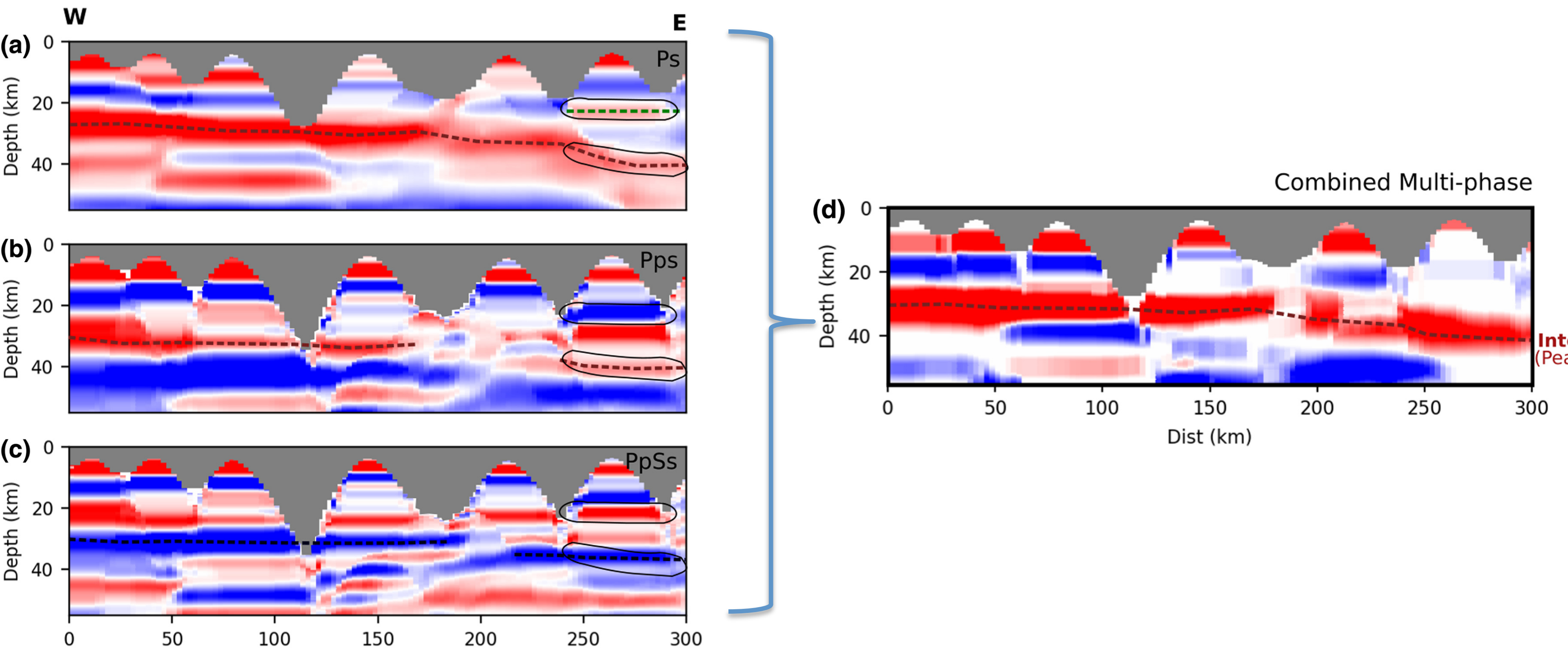
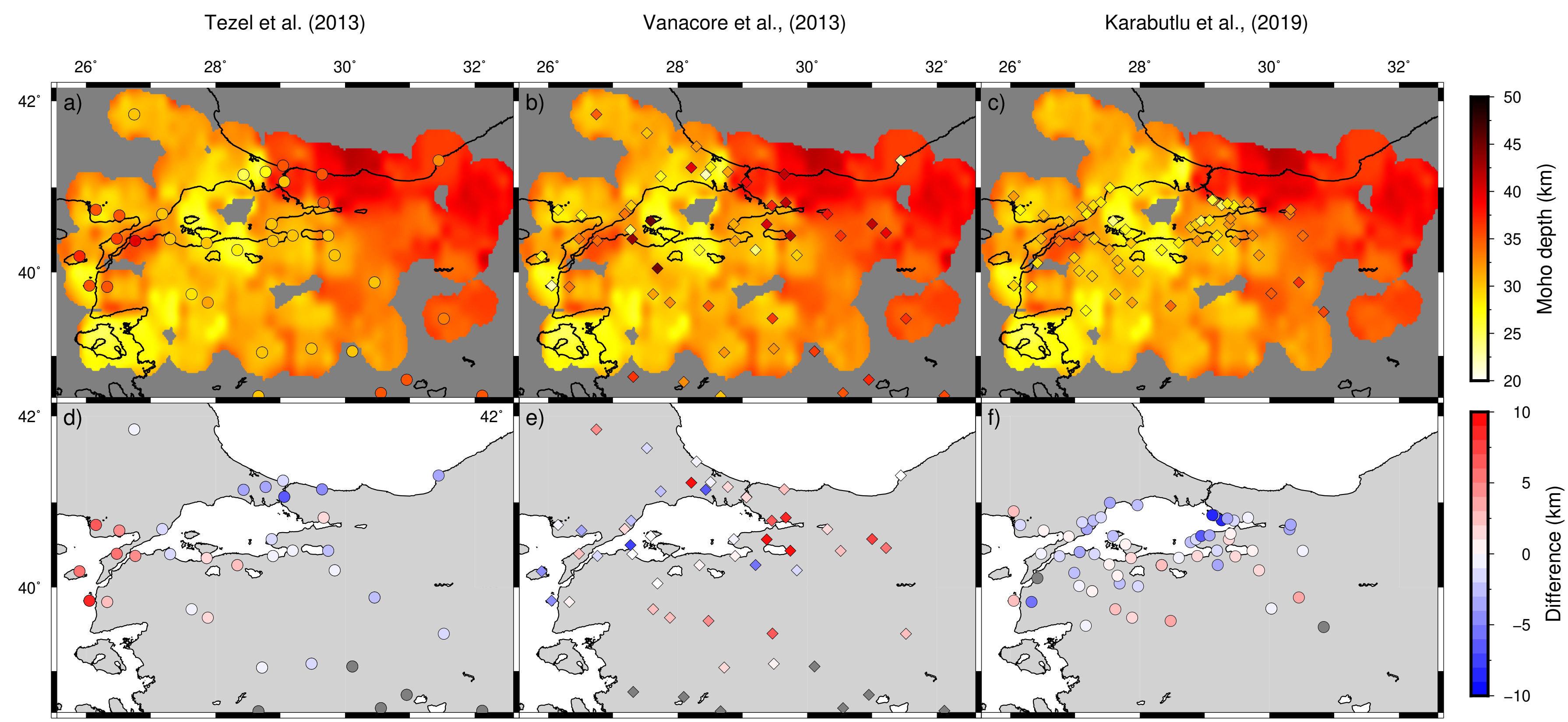
Extra details: Multi-phase CCP stacking - EXAMPLE

3 separate gridded CCP stacks are created from 3 different time to depth converted RF datasets for Ps, Pps and PpSs phases (show in left hand examples). These are combined to created a multi-phase stack where common features are observed within the 3 individual stacks. This removes ambiguity in the example below in the eastern end of cross-sections. In Ps stacks only it is unclear which arrival (~20km / 40km) is the Moho, but only the 40km arrival is supported by multiples in the other two stacks, thus this is picked int the multi-phase stack.



Note: PpSs arrivals (above) have opposite polarity (blue rather than red) to Ps and Pps phases

Extra details: Comparison to previous studies



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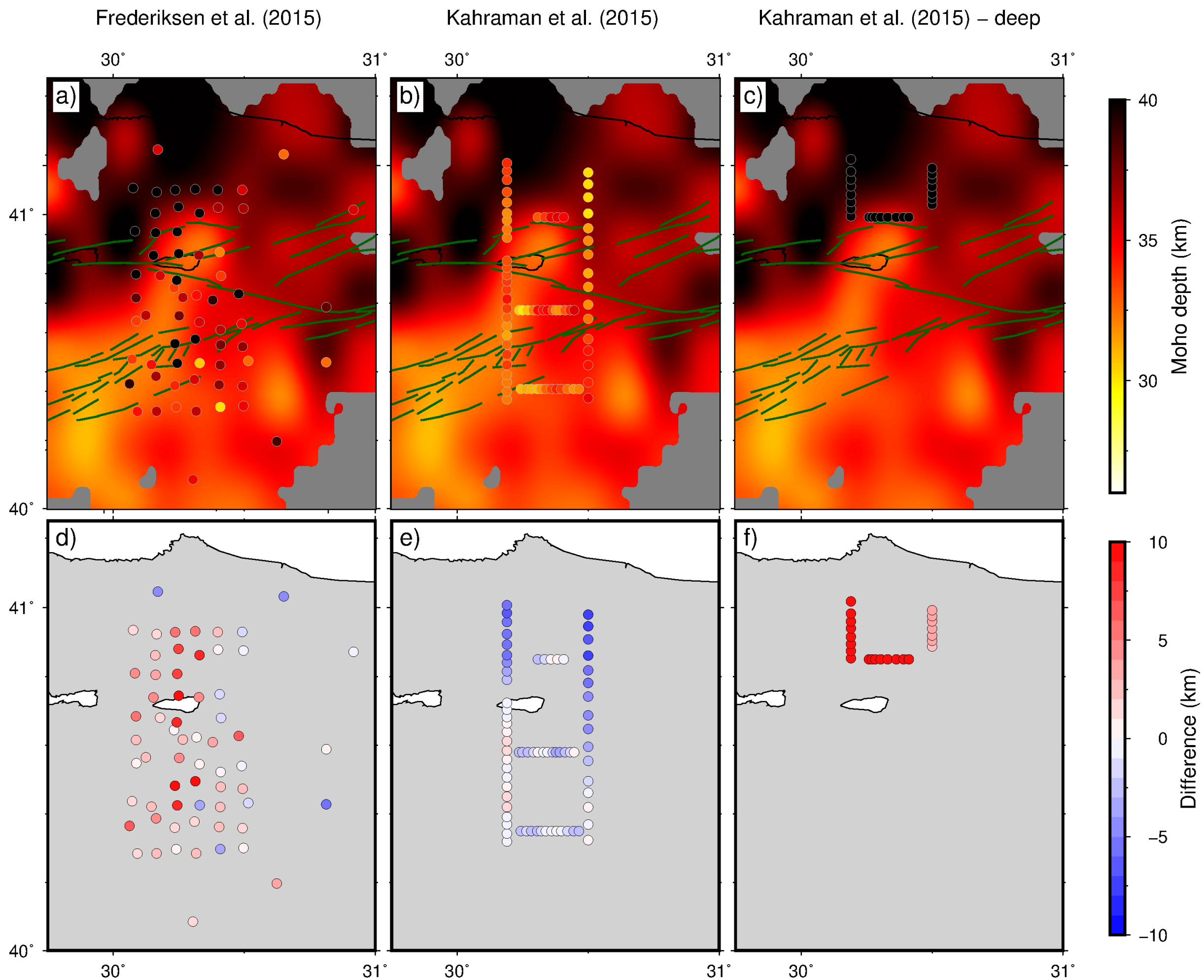
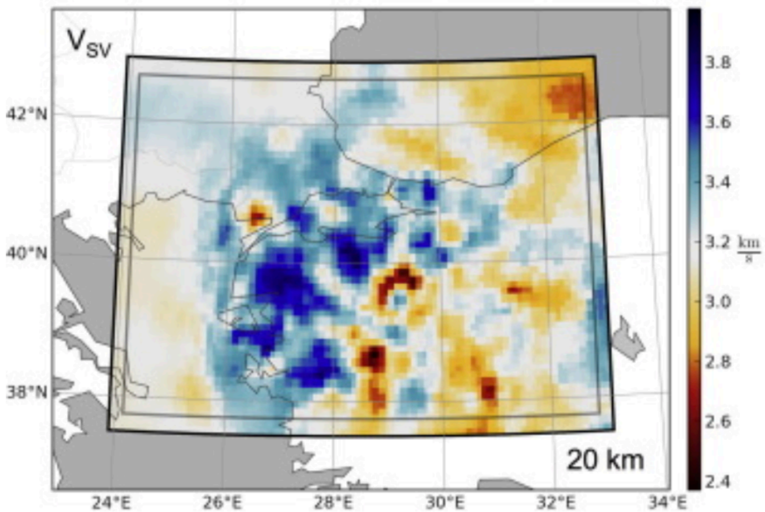


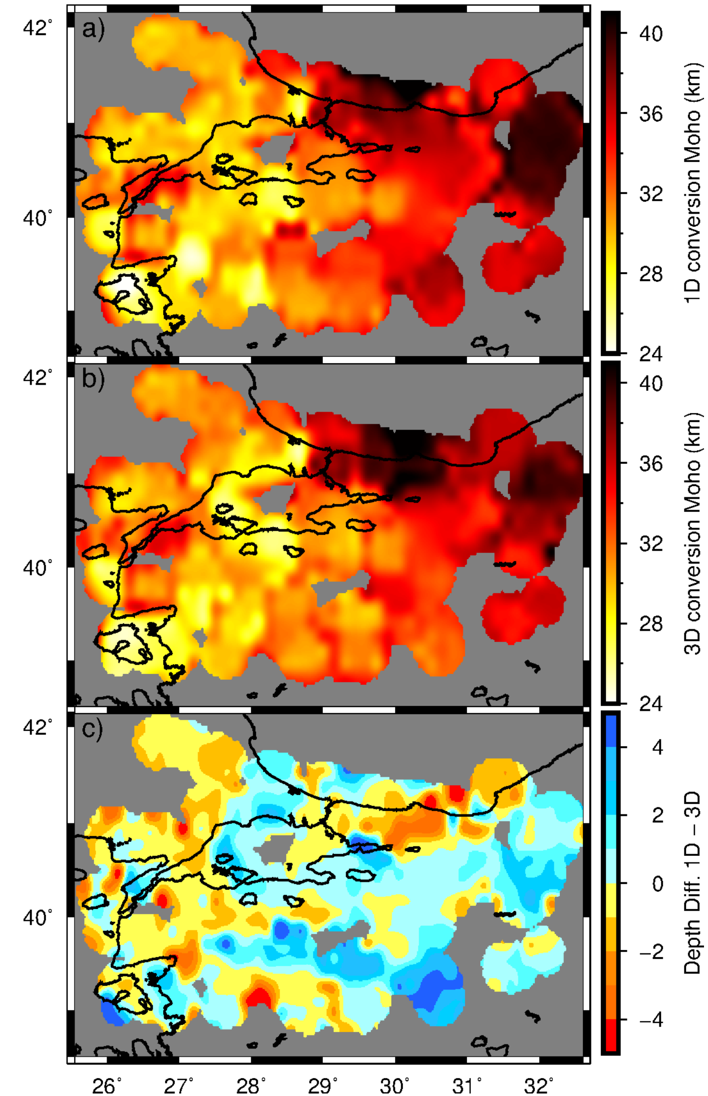
Extra details: velocity models

Comparisons to calculated Moho depths using 1D velocity model Karabutlu et al., (2011) and 3D velocity model (*Cubuk-Sabuncu et al., 2017)* - right.

Regional 3D full-waveform velocity model of Cubuk-Sabuncu et al., (2017) used in time-depth conversions - below.



Cubuk-Sabuncu et al., (2017)



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