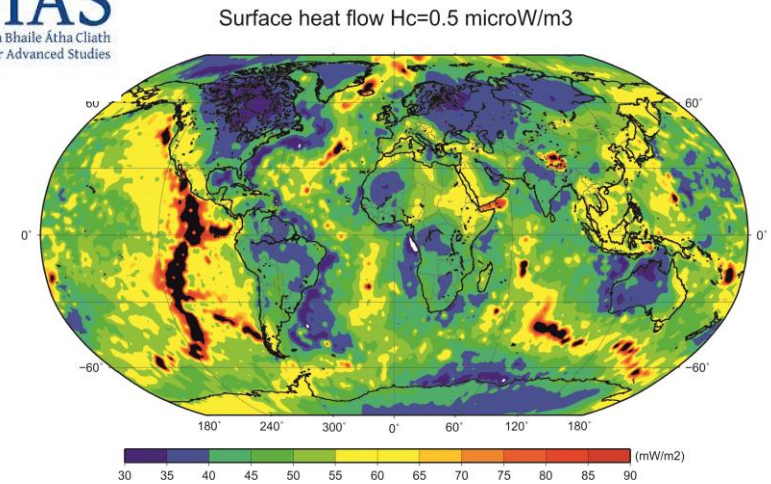
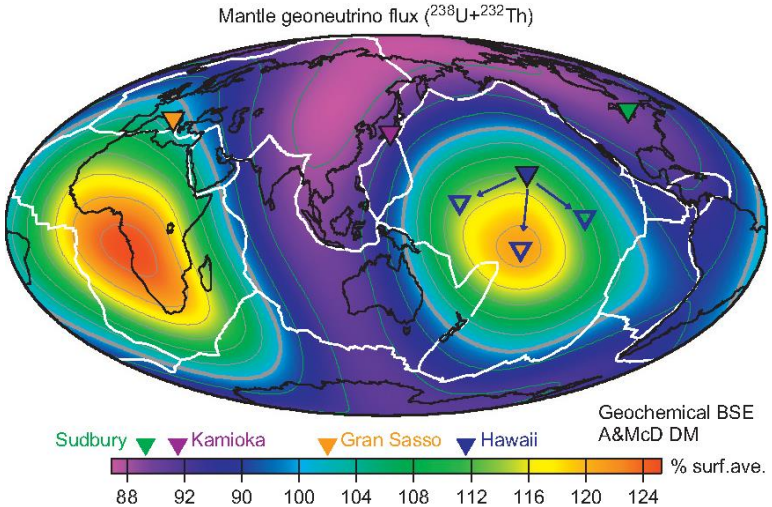
UNIVERSIDAD COMPLUTENSE MADRID

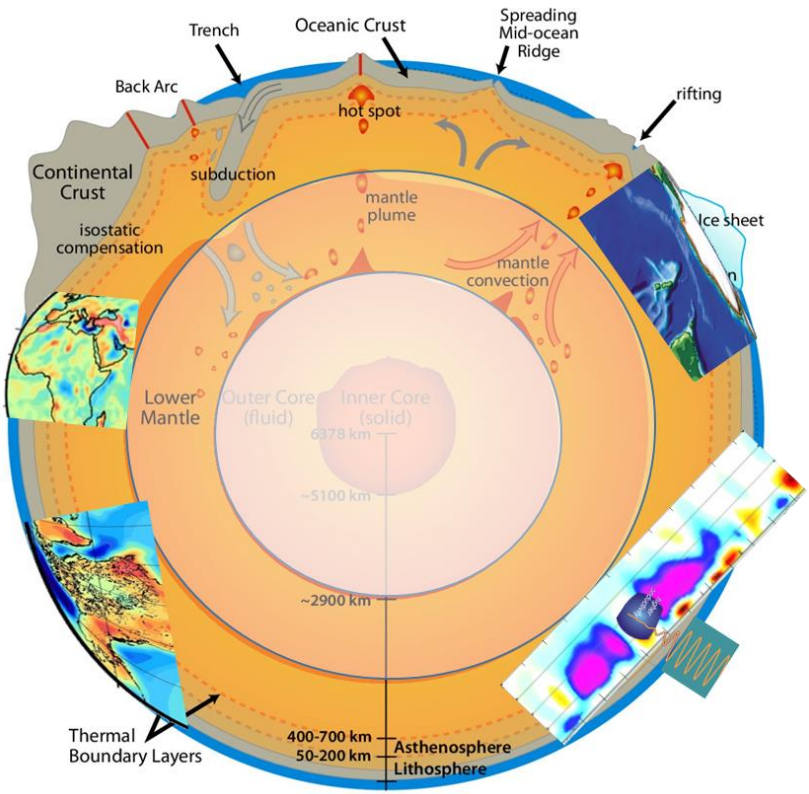
WINTERC-grav: a new upper mantle global thermochemical model from surface waveform tomography, heat flow, surface elevation and gravity satellite data.

DIAS
Institiúid Ard-Léinn Bhaile Átha Cliath
Dublin Institute for Advanced Studies



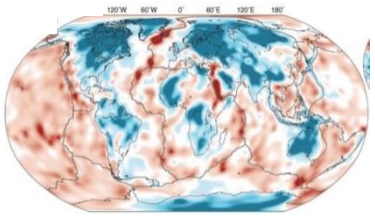


3D Earth – A Dynamic Living Planet



Many techniques/observations: just ONE Earth...

Seismic Velocity models



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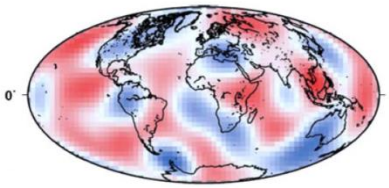
Electrical Conductivity models



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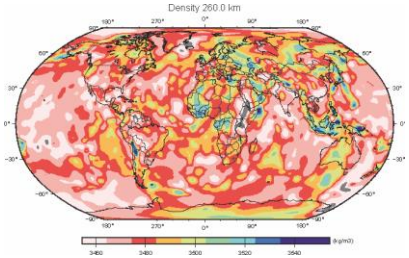
Density models



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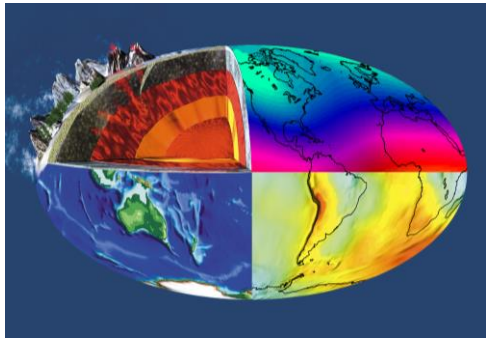
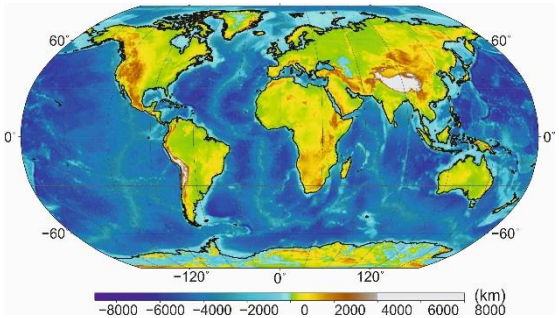
WINTERC-grav

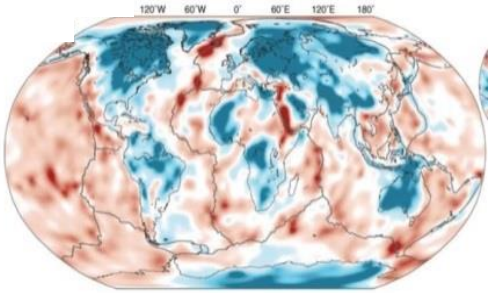
Satellite gravity

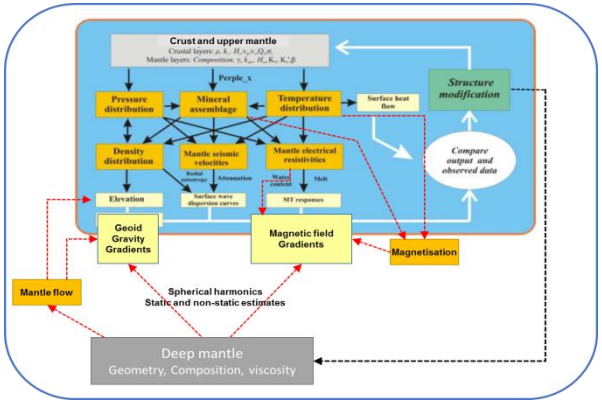


Topography



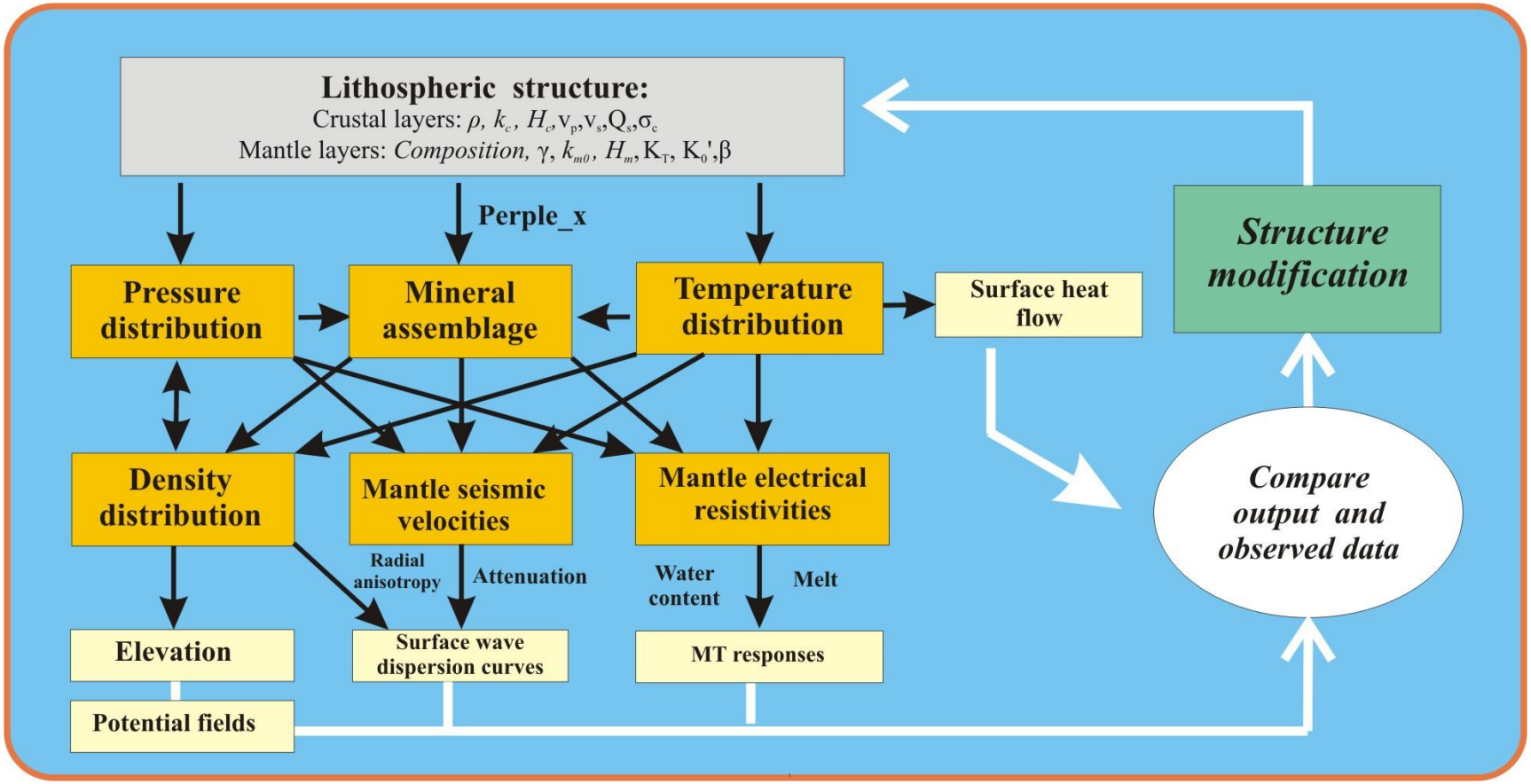
Seismic tomography





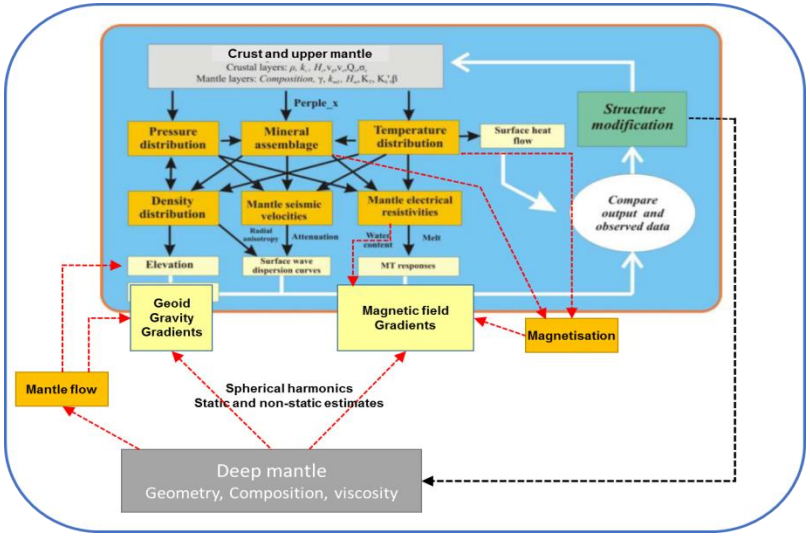
- ✓ **Jointly modelling seismic waveforms, elevation and satellite gravity data**
- ✓ **Sensitivity analysis of different data sets**

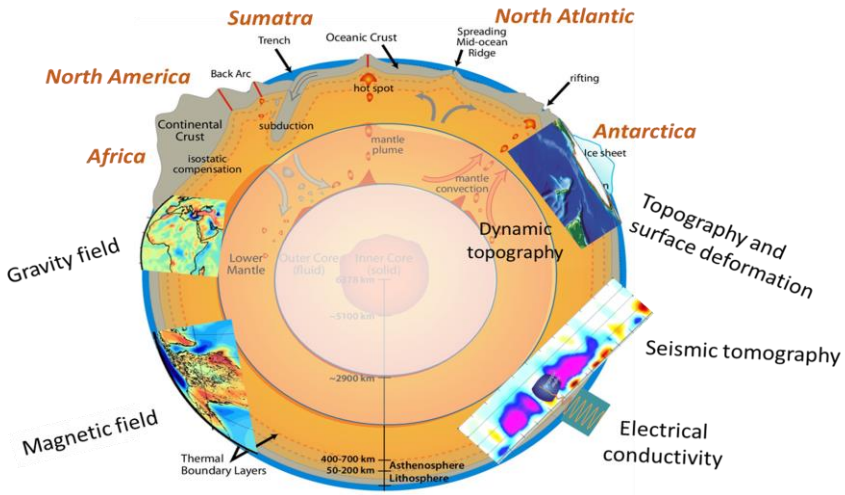
➢ Connect mineral physics & petrology & thermodynamics with geophysics



➢ *Integrated 1-,2- and 3-D forward and inversion regional modelling software:* ***LitMod*** *(Afonso et al., 2008, Fullea et al., 2009)*

WINTERC-grav





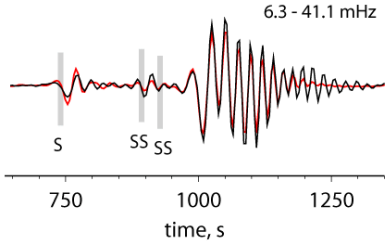
- ✓ **Two step global inversion:**
  - ❖ **Step 1 WINTERC: 1D- surface wave , surface elevation, heat flow**
  - ❖ **Step 2 WINTERC_Sph_harm: 3D- gravity field data**

- ✓ **Thermodynamic parameterization of physical properties (rho, Vs, Vp): LitMod built in**

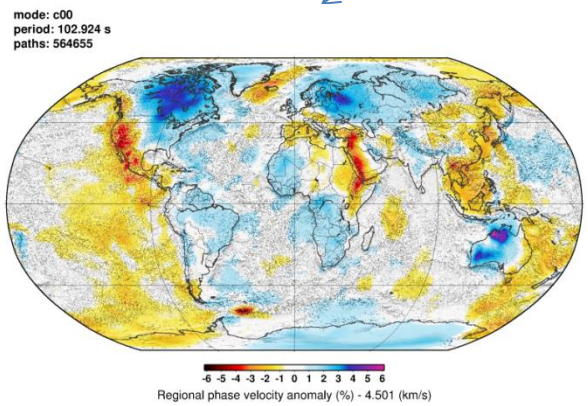
- ✓ **Focus on the lithosphere-uppermost mantle: temperature and composition**

WINTERC: seismic data

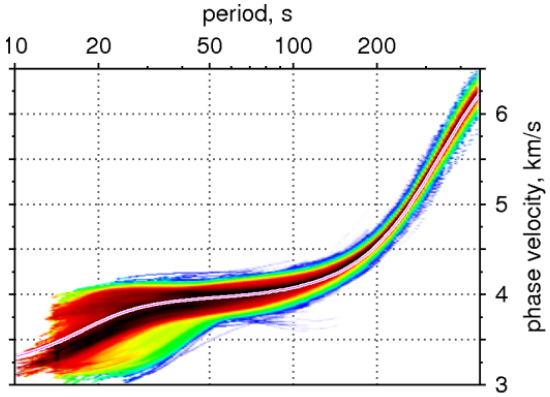
Waveform inversion



Seismogram reflecting Earth's structure along a path connecting earthquake and seismometer



2D Phase velocity maps

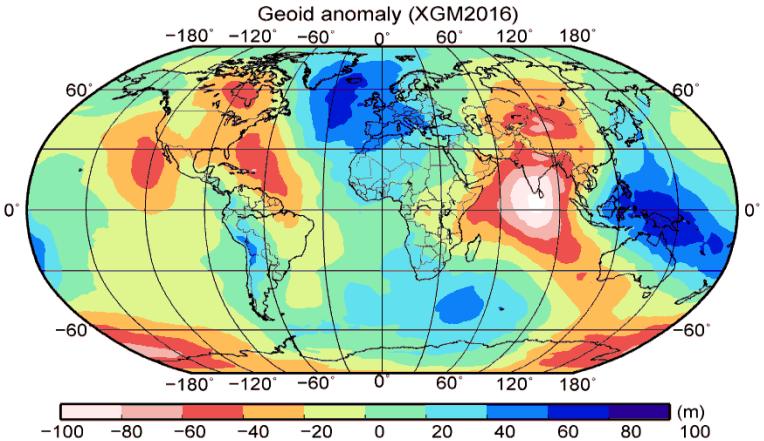


Phase velocity dispersion curves for each point (geographical coordinates grid).

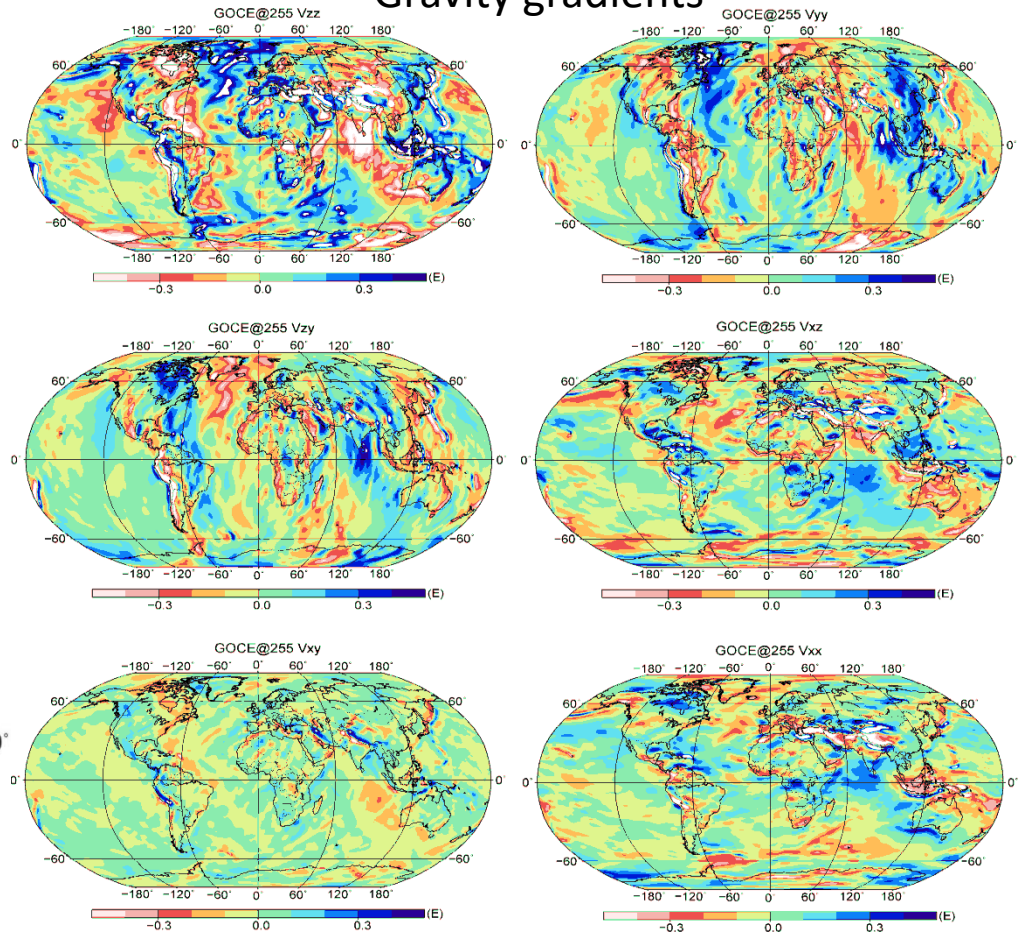
- ✓ 3D distribution of seismic velocities, currently using 6242 stations and 25496 events worldwide
- ✓ Sensitivity mostly to temperature and also composition
- ✓ 12,500 1D Columns (about 200 km inter knot spacing)

WINTERC-grav: gravity field & elevation data

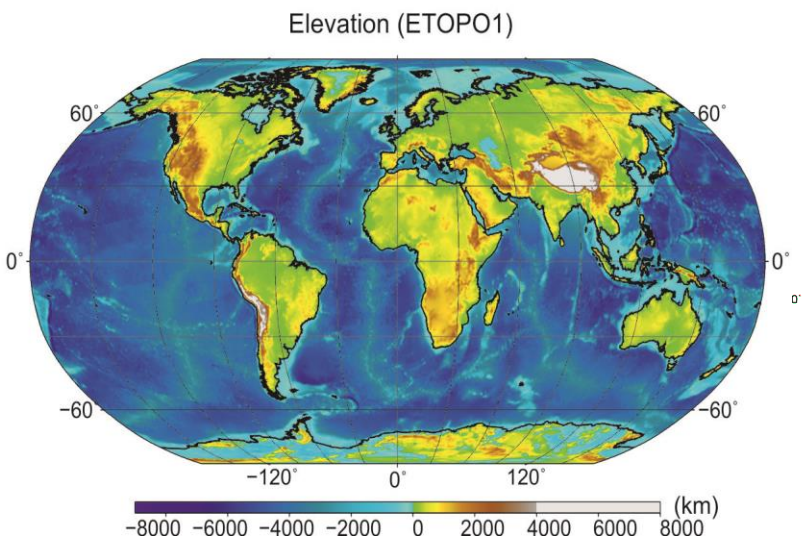
3D Satellite gravity data (GOCE, XGM2016)



Gravity gradients

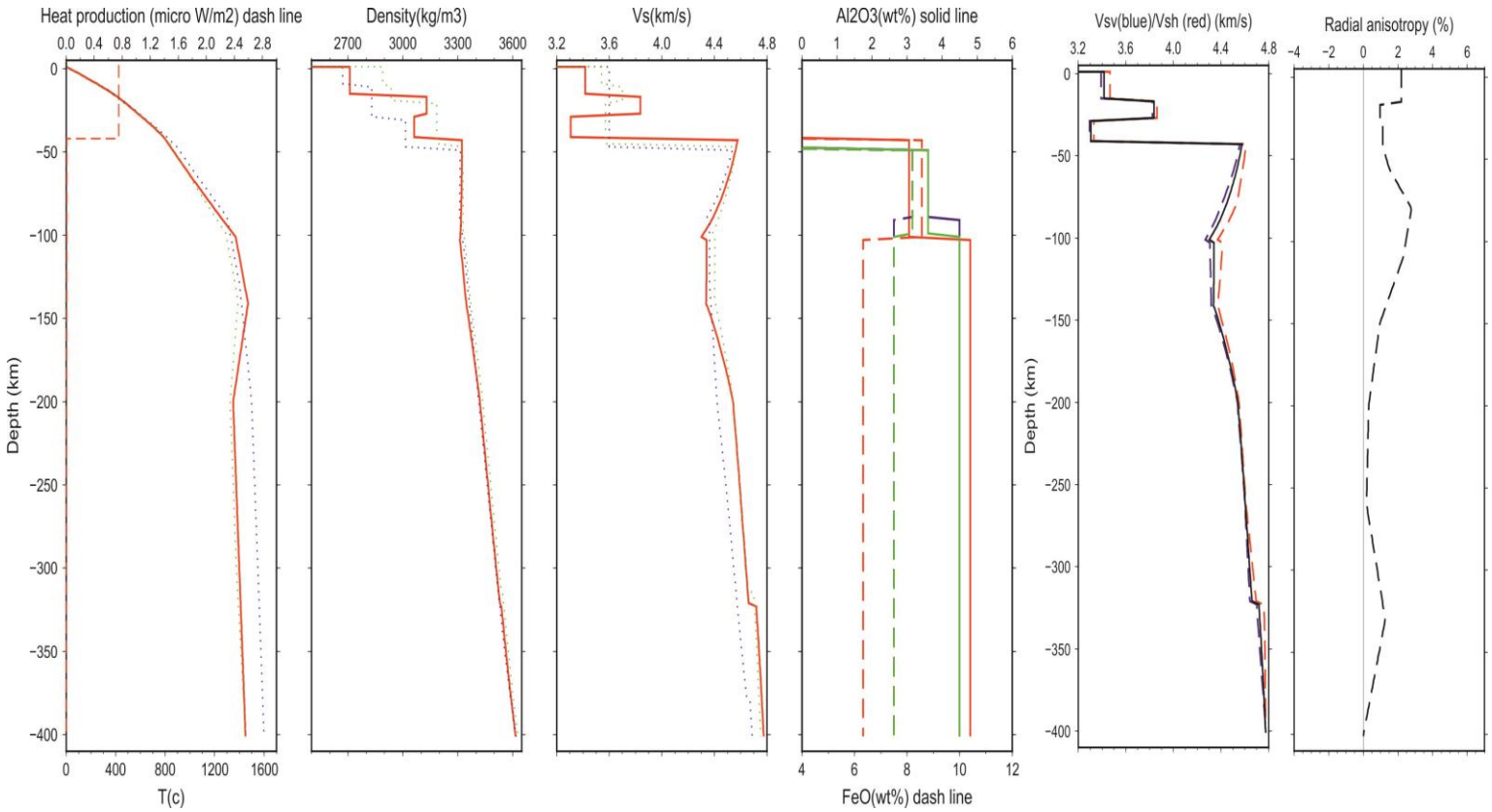


(Bouman et al., 2016.)



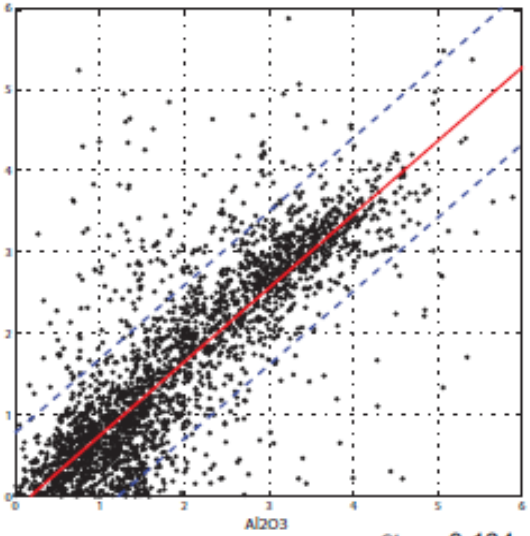
- ✓ Surface elevation is approximately in isostatic equilibrium (except dynamic topography)
- ✓ Sensitivity to density distribution
- ✓ Gravity data inversion: Intrinsically non-unique

WINTERC, step 1: inversion setting



- ✓ 1D Inversion of surface wave tomography data, elevation and heat flow
- ✓ Crustal structure: density, seismic velocities, heat production and thickness
- ✓ Mantle structure: Thermal lithosphere (LAB) and sublithospheric temperature; mantle composition

WINTERC, step 1: inversion setting

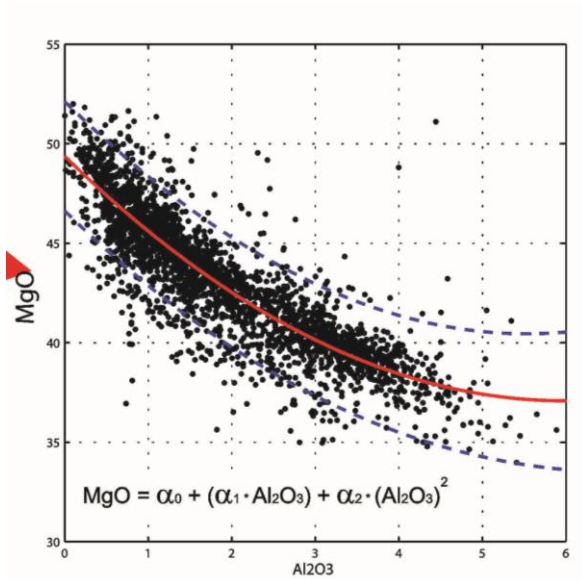


$CaO = \alpha_0 + \alpha_1 * Al_2O_3$

$R^2 = 0.674$

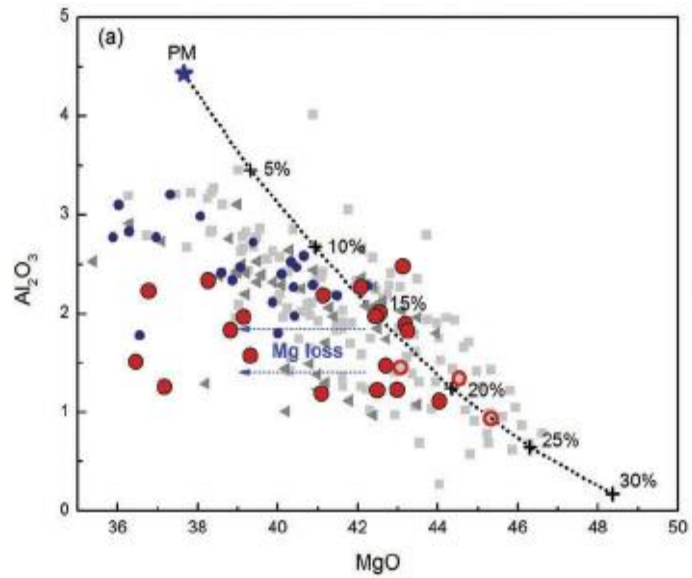
$\alpha_0 = -0.164$

$\alpha_1 = 0.906$



$MgO = \alpha_0 + (\alpha_1 \cdot Al_2O_3) + \alpha_2 \cdot (Al_2O_3)^2$

$\alpha_0 = 49.369 \quad \alpha_1 = -4.106 \quad \alpha_2 = 0.343$



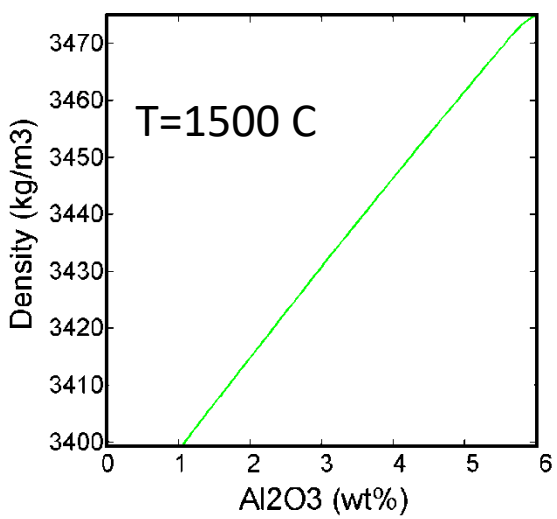
* Correlation between oxides regardless of tectonic age or facies from petrological data base (>2900 samples from xenoliths, perid. Massifs and ophiolites) (Afonso et al., 2013)

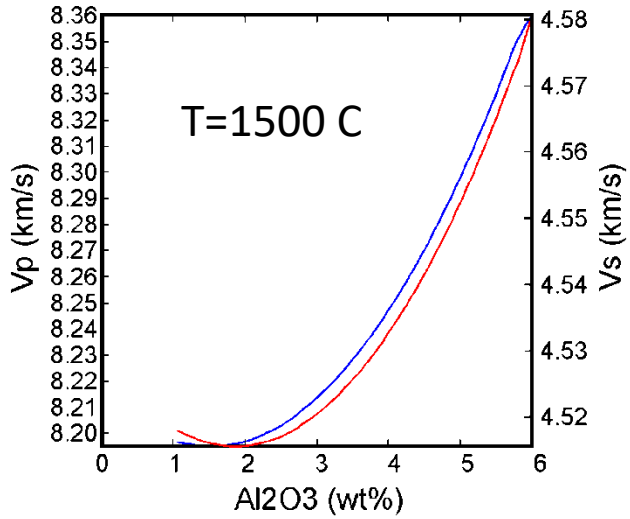
Melting trend

- ✓ Mantle composition described by **Al2O3** and FeO independent variables (CaO and MgO=F(Al2O3))
- ✓ Chemical parameterization following melting trend, analogous to pyrolite (Harz+basalt)

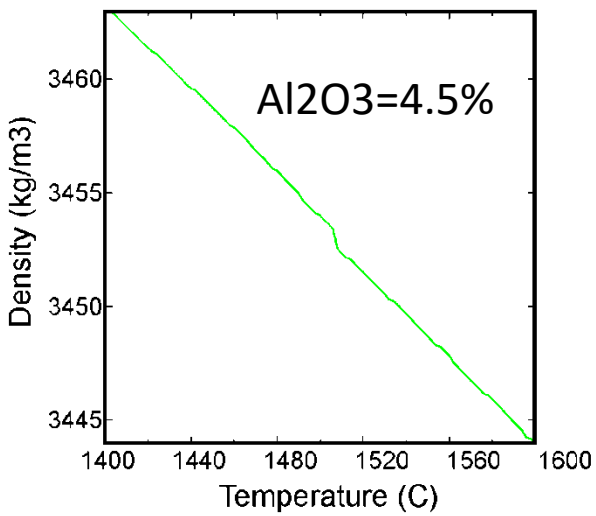
WINTERC-grav, step 2: inversion setting

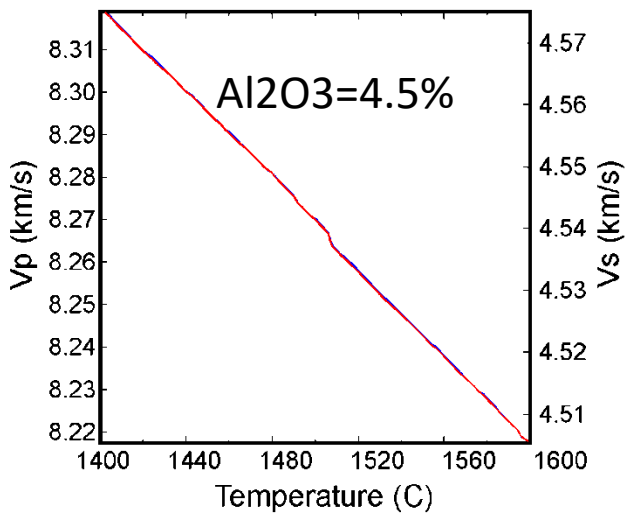
Physical properties-derivatives @ P=7.6 Gpa and FeO=7.9 wt% (Perple_X)





Chemical derivative
For drho=15 kg/m3→ dAl2O3=1wt% (dVs=0.2%)



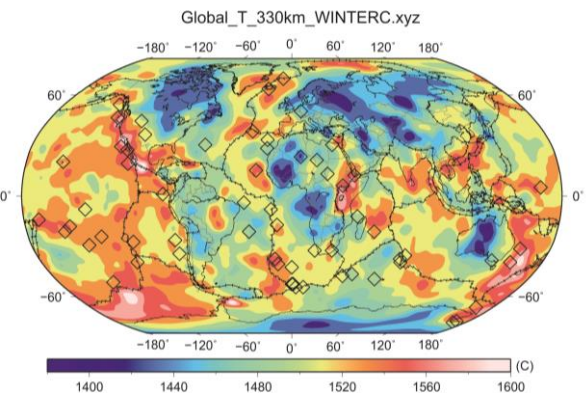


Temperature derivative
For drho=15 kg/m3→ dT=200 C(dVs=1.8%)

V's variations are comparable, ***drho/dAl2O3=150* drho/dT***

WINTERC-grav, step 2: gravity field

- ✓ 3D Gravity data inversion regularized by temperature composition from WINTERC (step1: surface wave data)
- ✓ Variables for the gravity inversion are the composition (Al2O3) of lithosphere and sublithosphere and crustal density
- ✓ Geoid anomaly constrains upper mantle density, gravity grads@255 km constrain crustal density



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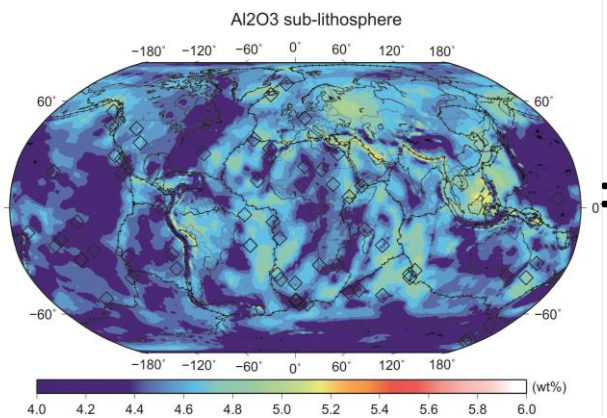

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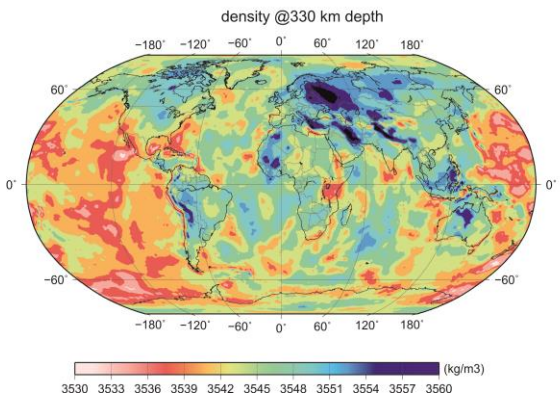
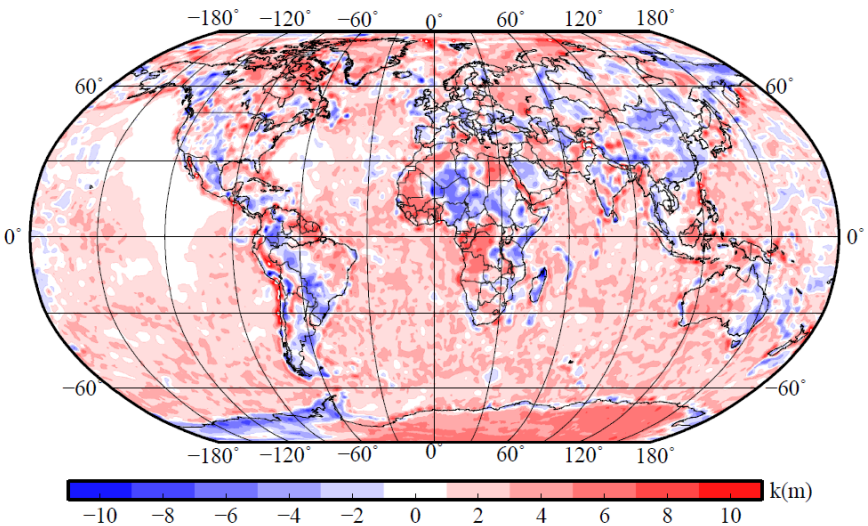
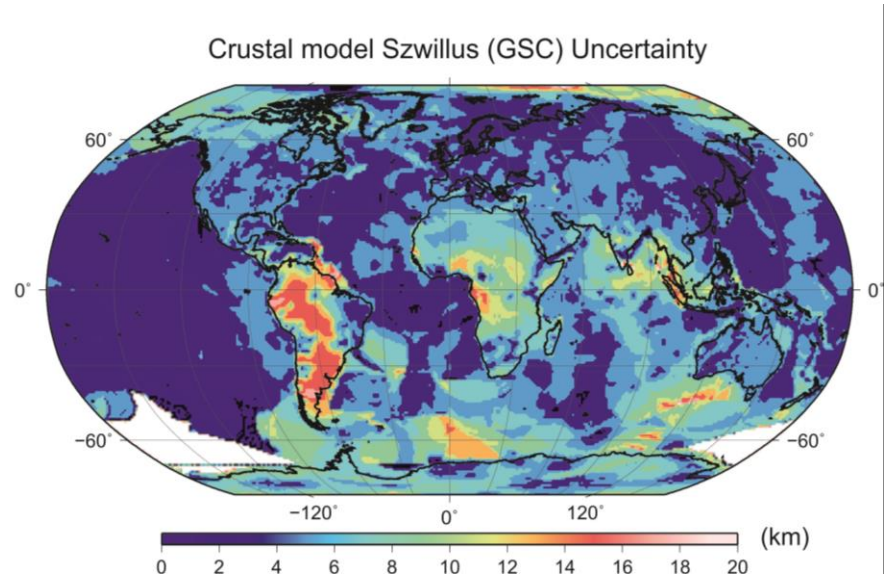
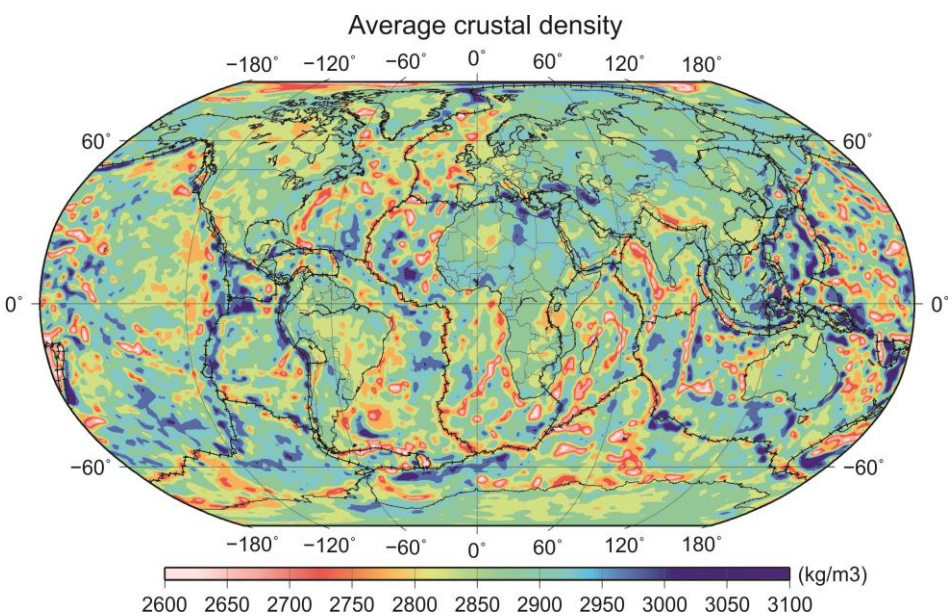


WINTERC-grav: new crustal model

Differences in crustal thickness for WINTERC_grav with respect to CRUST1.0 (within the uncertainties statistically estimated from Szwillus et al., 2019)

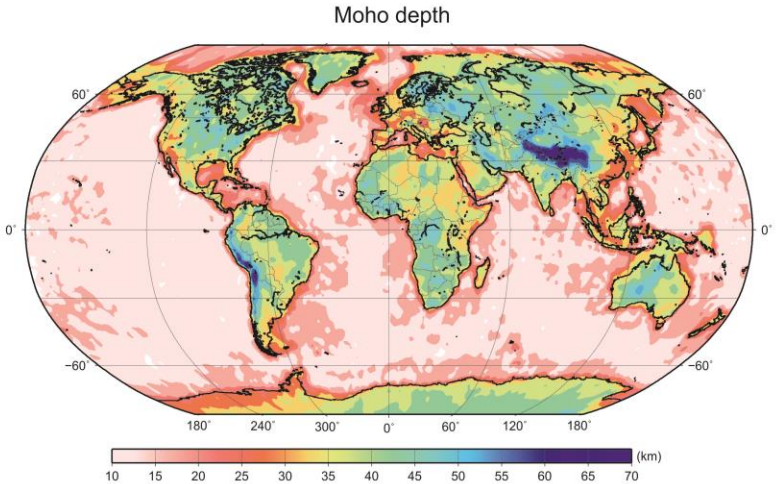


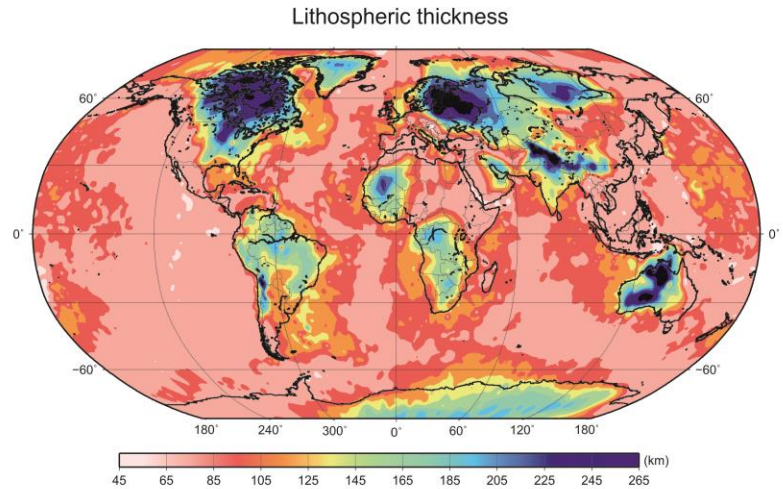


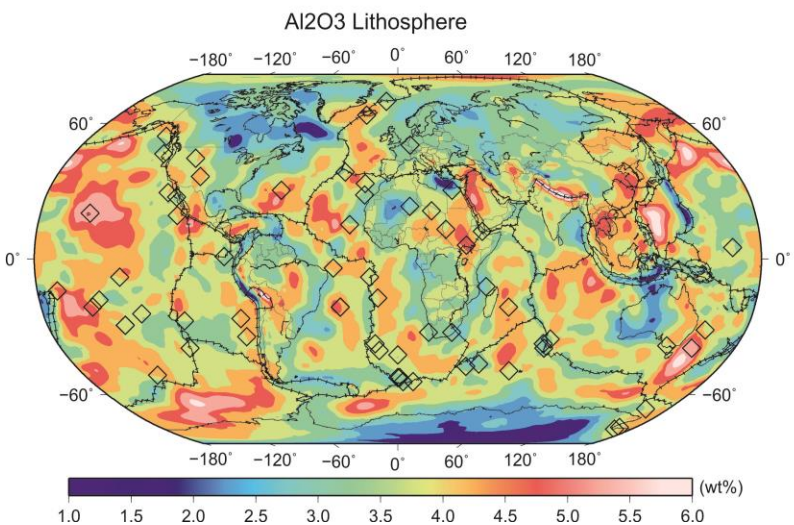


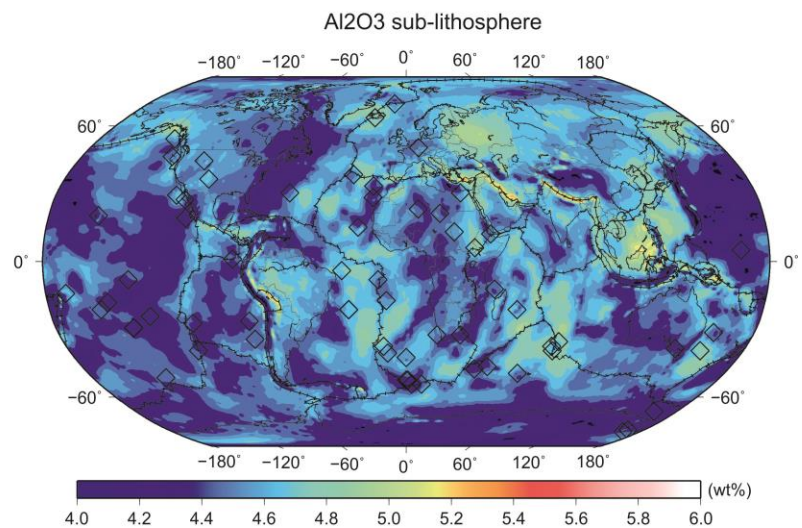
- ✓ Geometry (Moho depth, upper-mid/lower crust)variations
- ✓ Vs, Vp upper-mid/lower crust
- ✓ Average density

WINTERC-grav: Lithosphere & composition



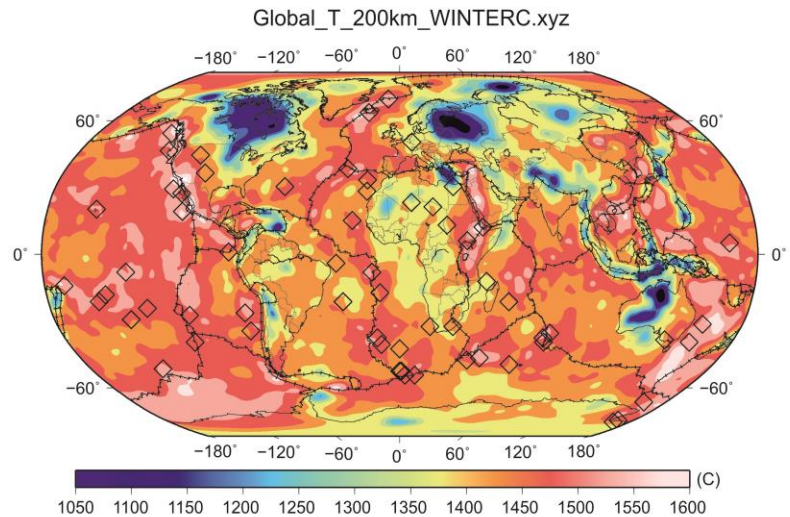


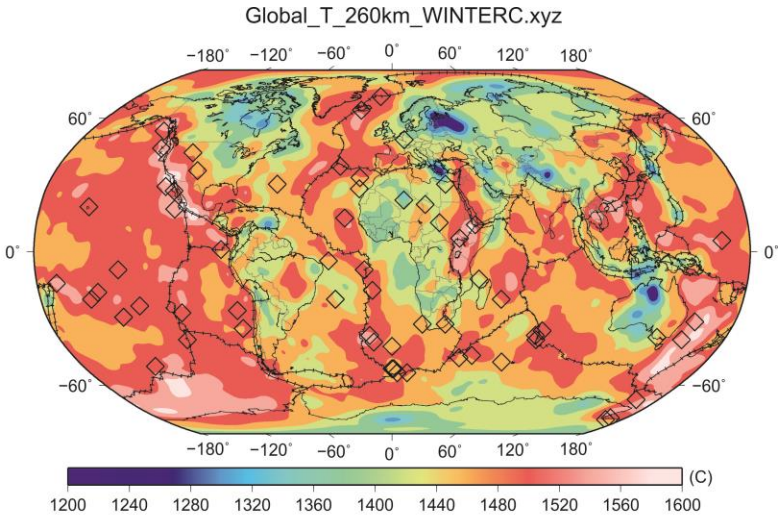


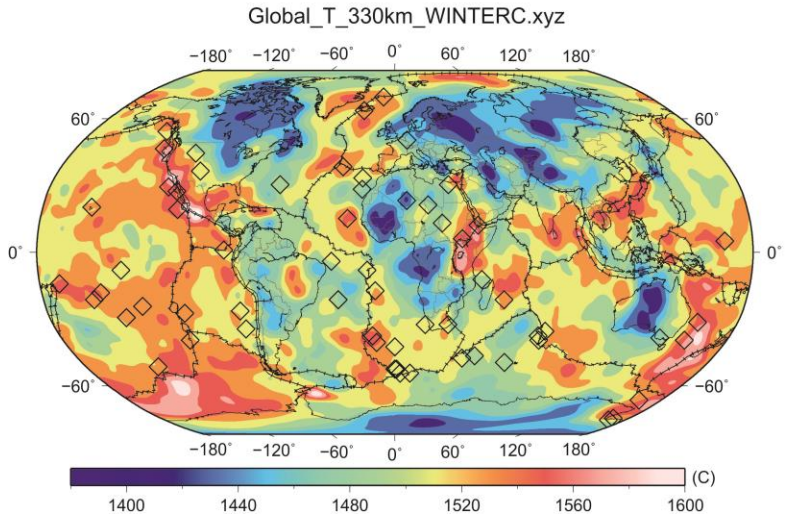


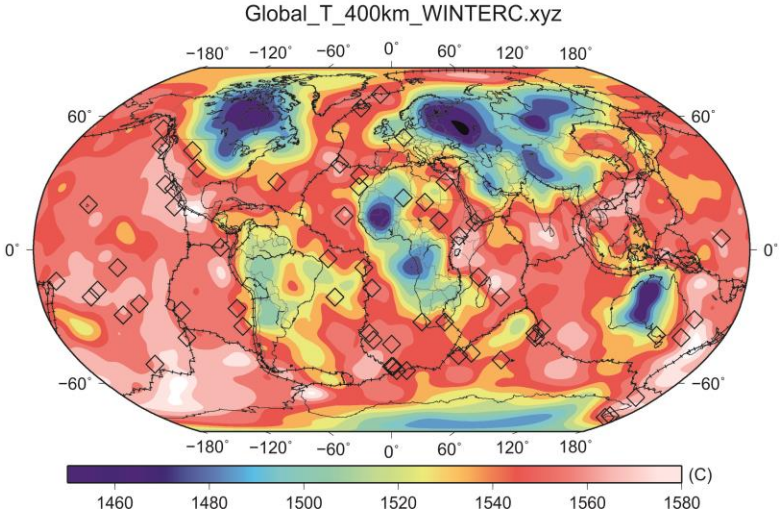
- ✓ Thermal and compositional lithosphere
- ✓ High Al2O3→fertile, low Mg#, Low Al2O3→refractory, high Mg#,

WINTERC-grav: temperature



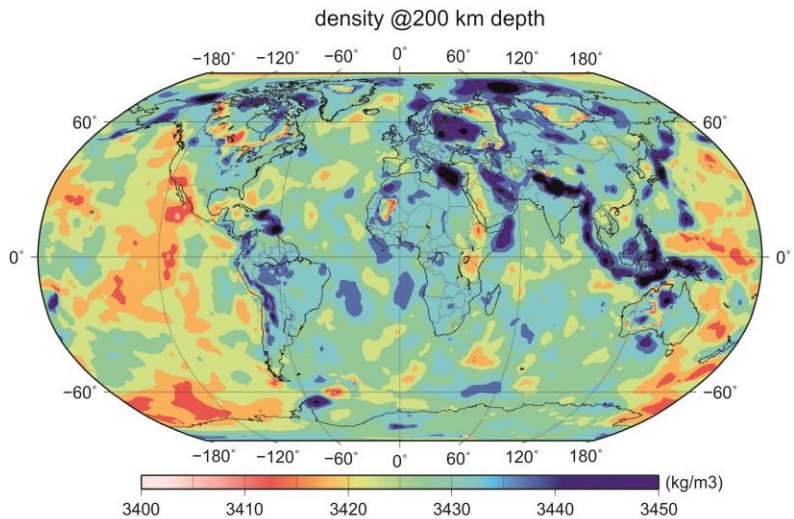


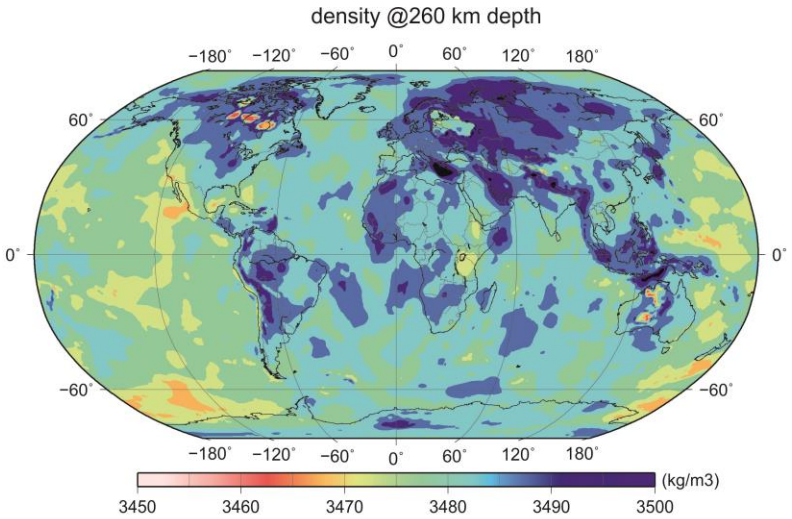


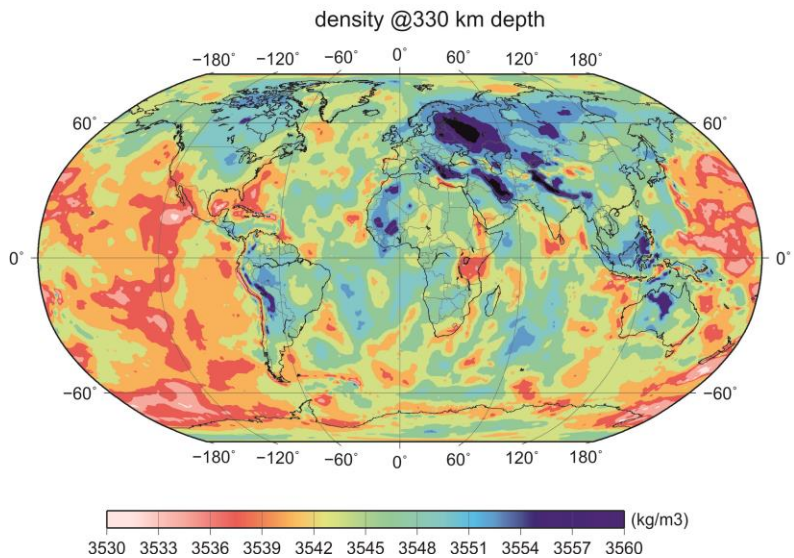


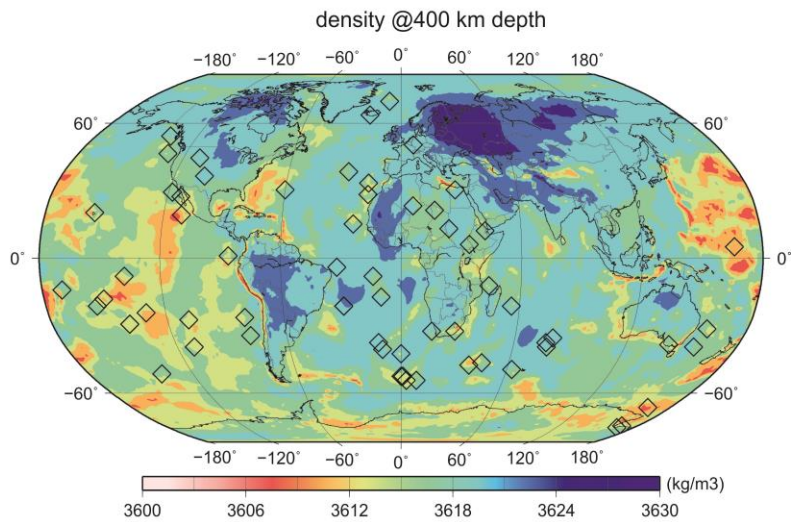
- ✓ Average adiabatic gradient 0.55-0.6 K/km (depth >200 km)
- ✓ Average mantle potential temperature 1300-1320 C (depth >200 km)

WINTERC-grav: density (T,C)





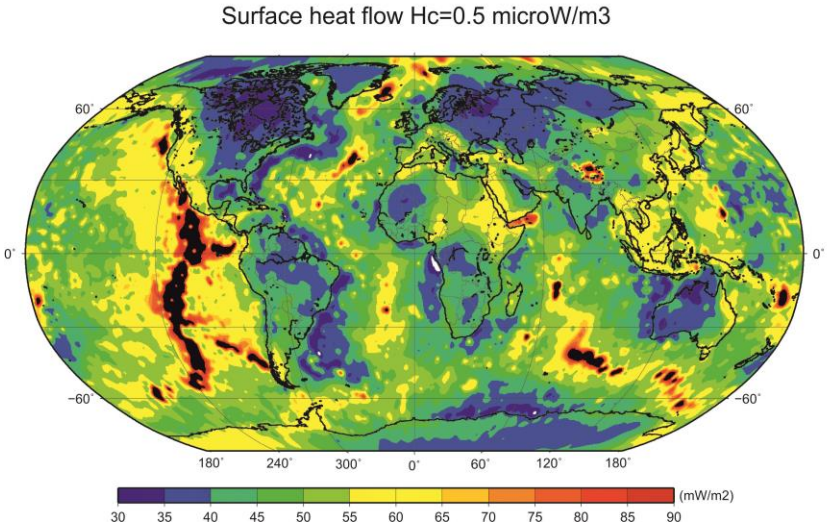




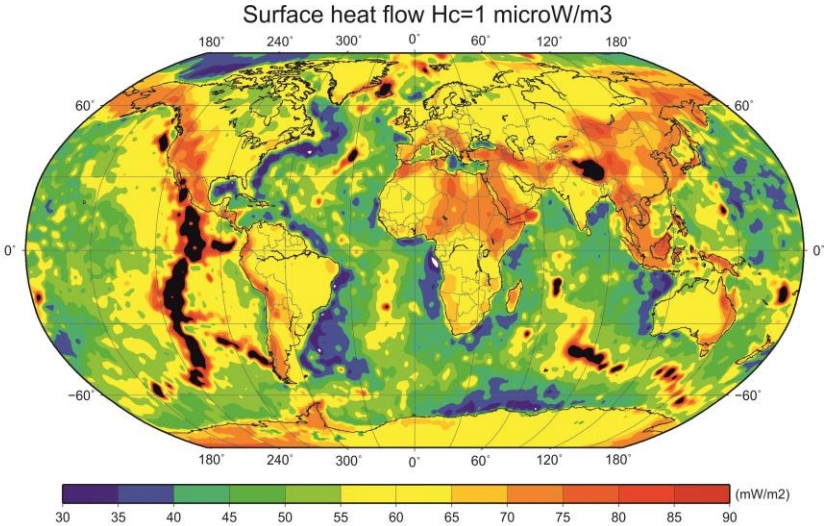
✓ Density=F(temperature, Composition)

WINTERC-grav: Surface heat flow + energy budget

Hc =Cont 0.5/Ocean 0.1 microW/m3



Hc=Cont 1/Ocean 0.1 microW/m3



E_tot=25.6 TW (Cont.=8.6TW/Ocean=17 TW)

SHF_av Cont.=45.6 mW/m2/ocean= 52 mW/m2

E_rad_crust=3.8 TW(Cont.=3.5 TW/ocean 0.3 TW)

E_rad_mant_litho=0.4 TW (Cont.=0.17 TW/ocean 0.23 TW) (Hm=0.01microW/m3)

E_tot=29.1 TW (Cont.=12.1TW/Ocean=17 TW)

SHF_av Cont.=64.4 mW/m2/ocean= 52 mW/m2

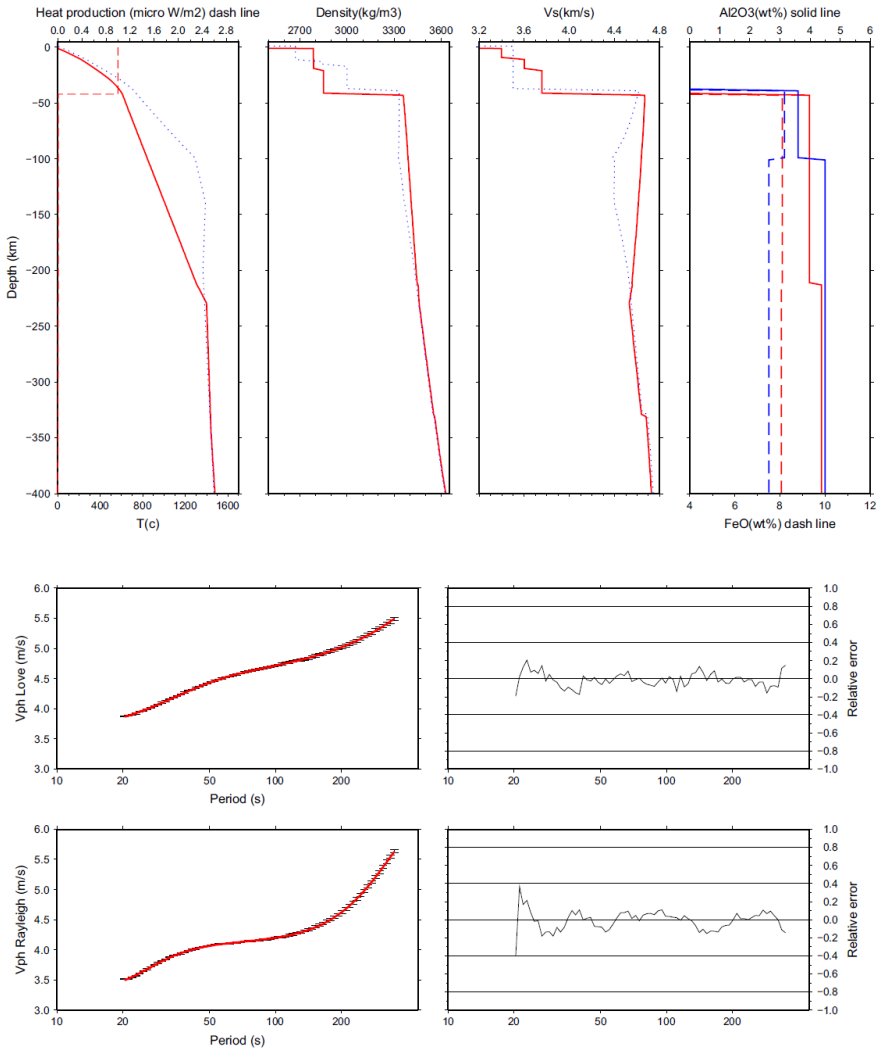
E_rad_crust=7.3 TW(Cont.=7 TW/ocean 0.3 TW)

E_rad_mant_litho=0.4 TW (Cont.=0.17 TW/ocean 0.23 TW) (Hm=0.01microW/m3)

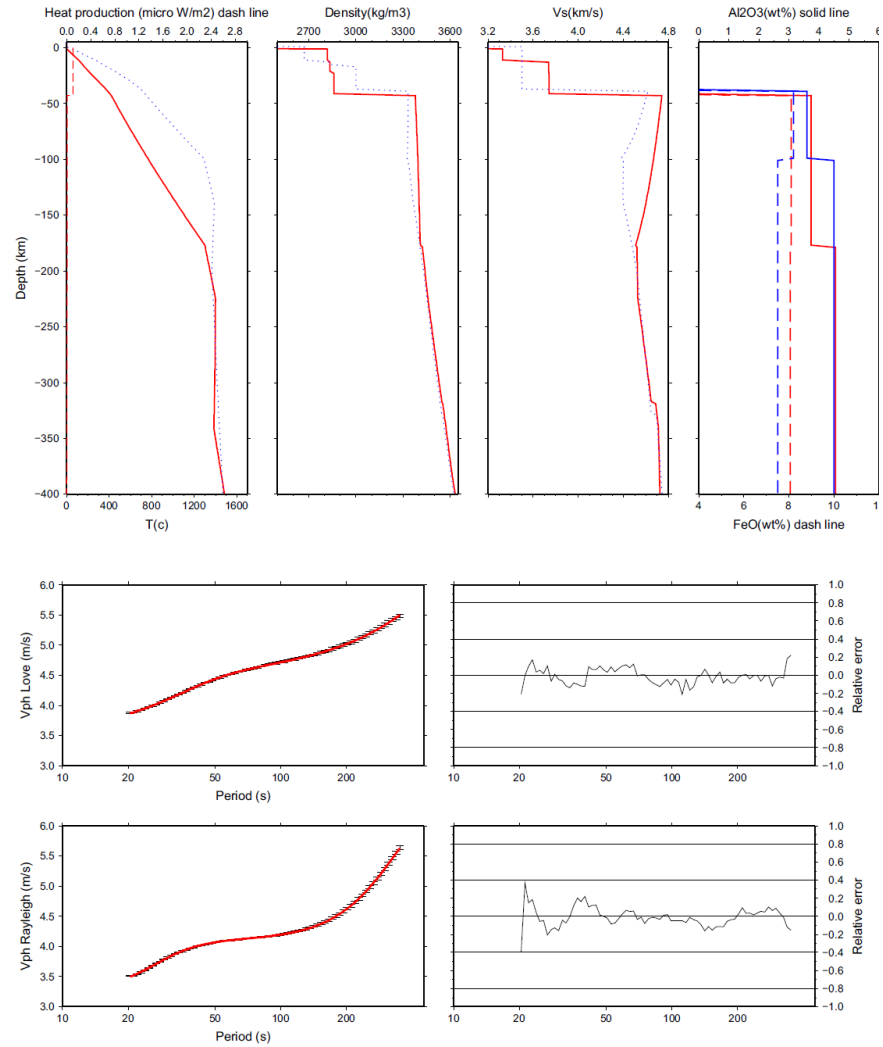
E_tot=47 TW (Cont.= 14TW/ocean=32TW) ; **SHF_av** Cont.=65 mW/m2/ocean= 94 mW/m2 E_rad_lithosphere=8TW (Jaupart et al. 2015)

WINTERC: sensitivity to crustal radiogenic heat, Hc

SHF=52 mW/m2, Hc=1microW/m3

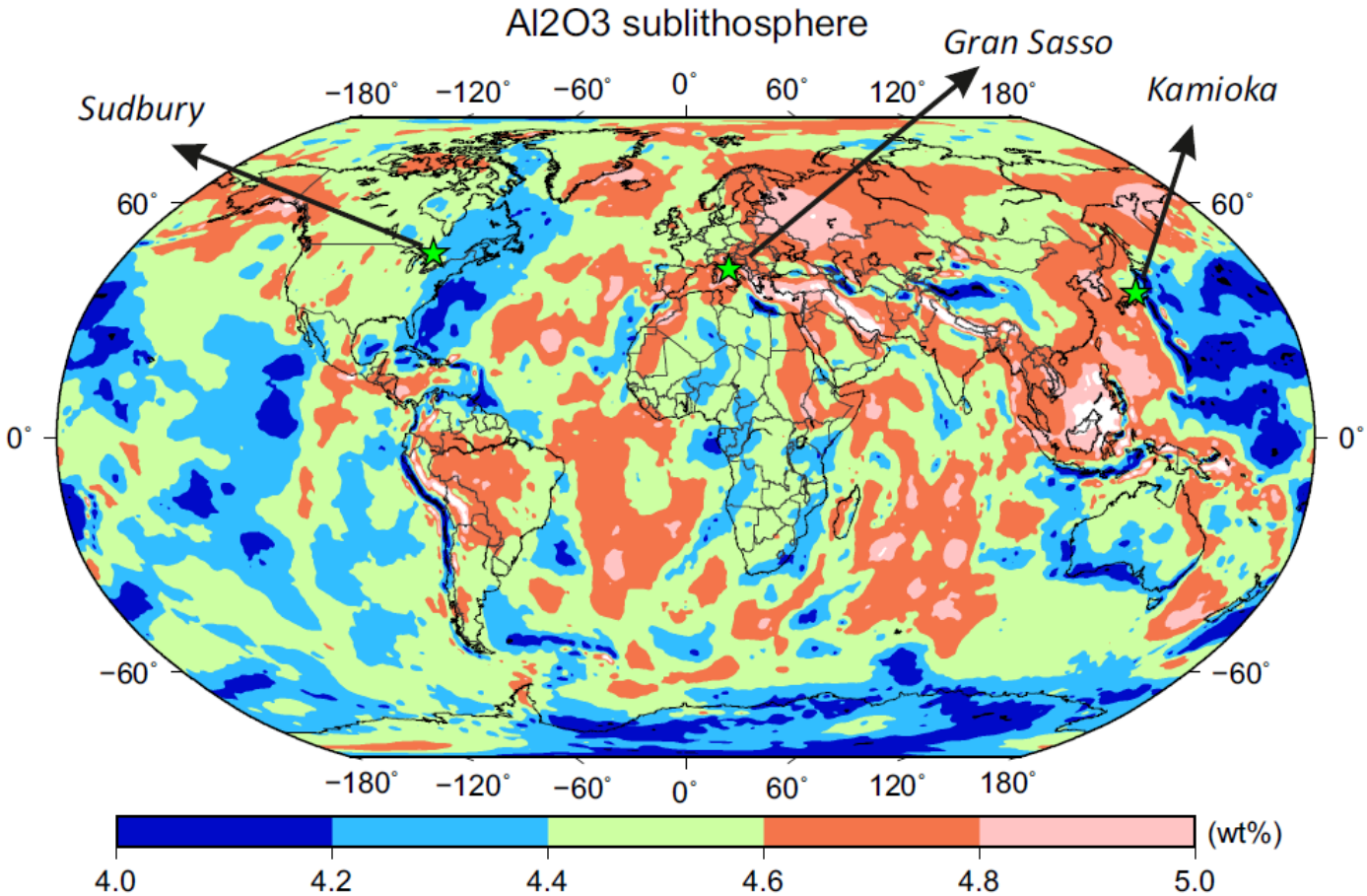


SHF=25 mW/m2 Hc=0.1microW/m3



✓ Hc controls output SHF and affects crustal structure (rho, Vs=F(lithology, Temperature))

WINTERC-grav: mantle composition

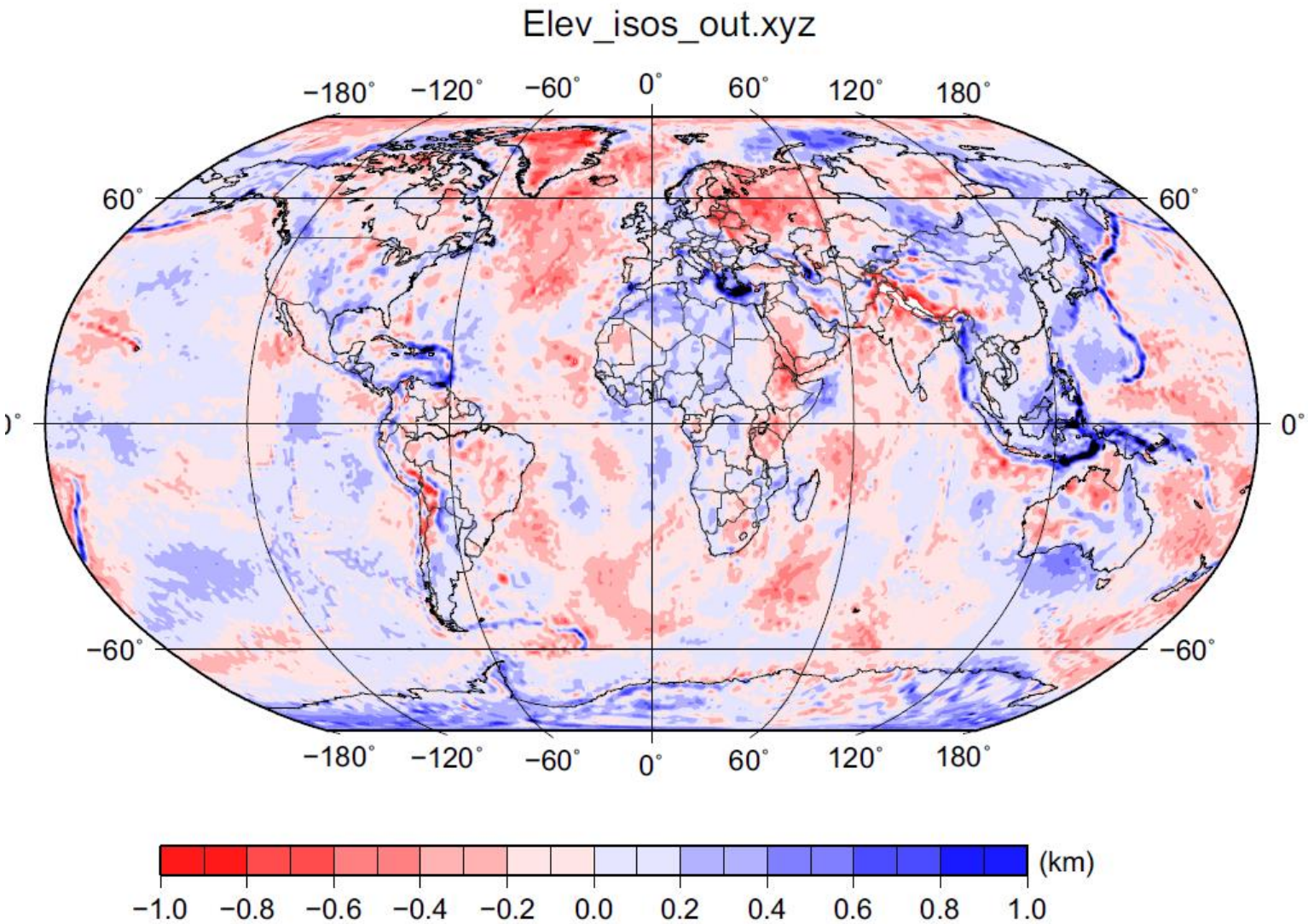


- ✓ High Al2O3→fertile, low Mg#, Low Al2O3→refractory, high Mg#,
- ✓ Fertility lateral variations in the upper mantle: proxy for (upper) ***mantle radiogenic heat*** variations?
- ✓ Define ***near field mantle*** for geoneutrino emissions??

Conclusions

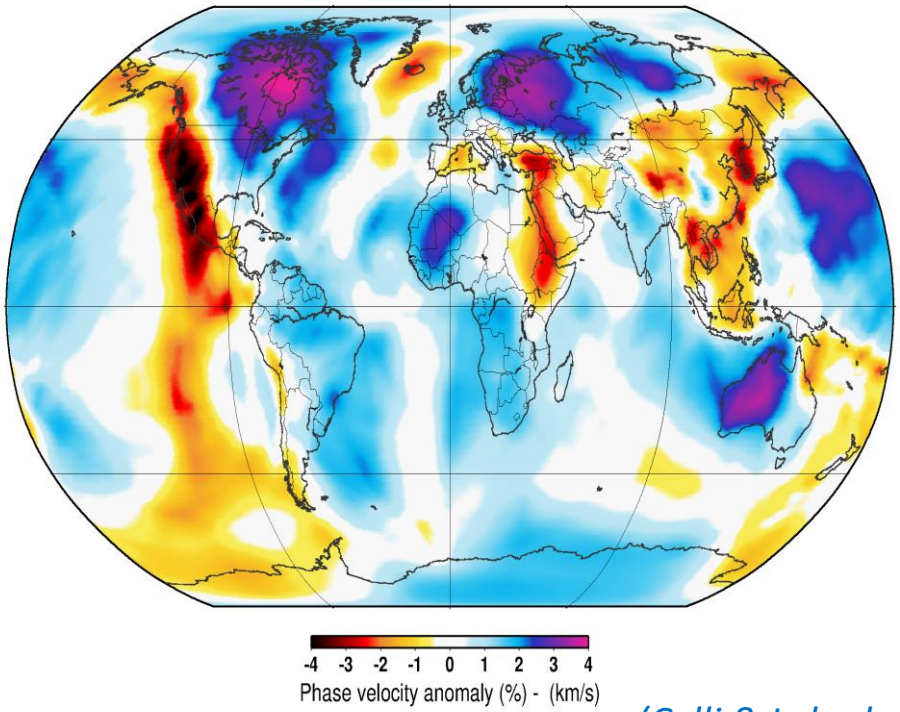
- ✓ WINTERC-grav: new global lithospheric/upper mantle thermochemical model
- ✓ New crustal mode revisiting Crust1.0: geometry, density
- ✓ Potential to constrain crustal heat production: surface heat flow and petrological parameterization of crust Vs, rho=f(T,P, litho)
- ✓ Upper mantle bulk composition (major elements), proxy for radiogenic heat? Near field mantle geoneutrino signal??

WINTERC-grav: isostatic/dynamic elevation

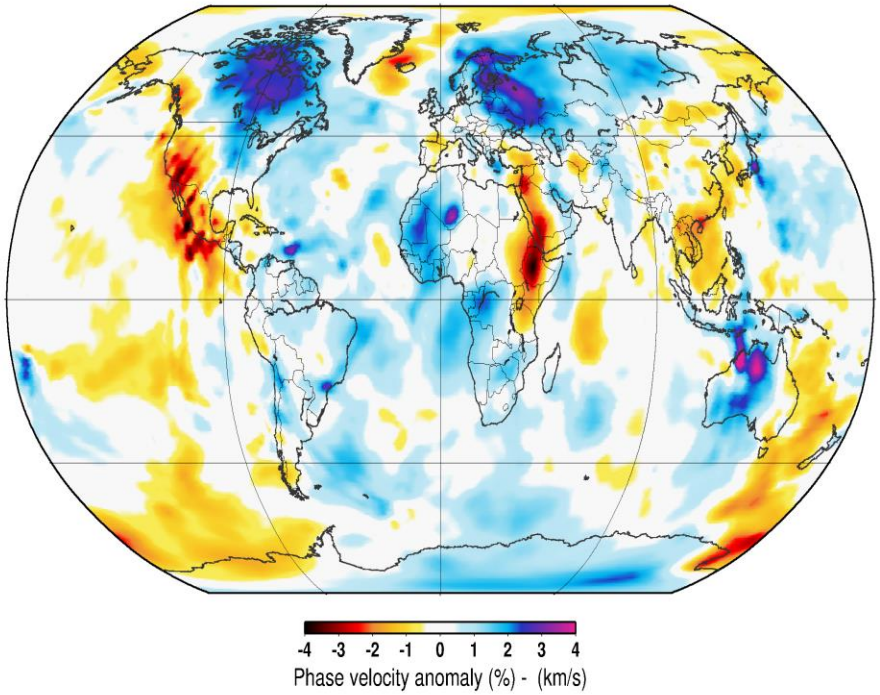


WINTERC: seismic data

Love @150 s



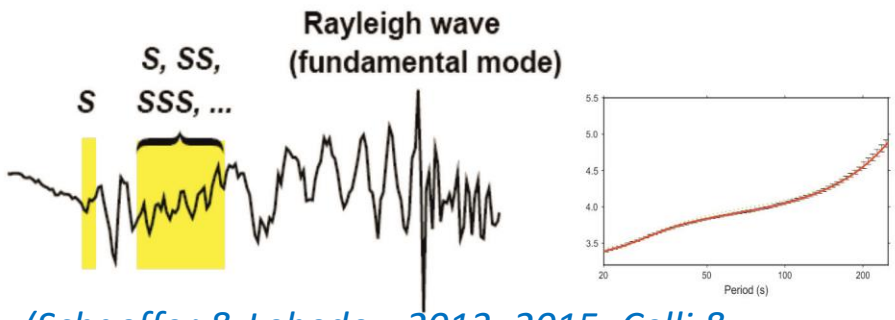
Rayleigh @150 s



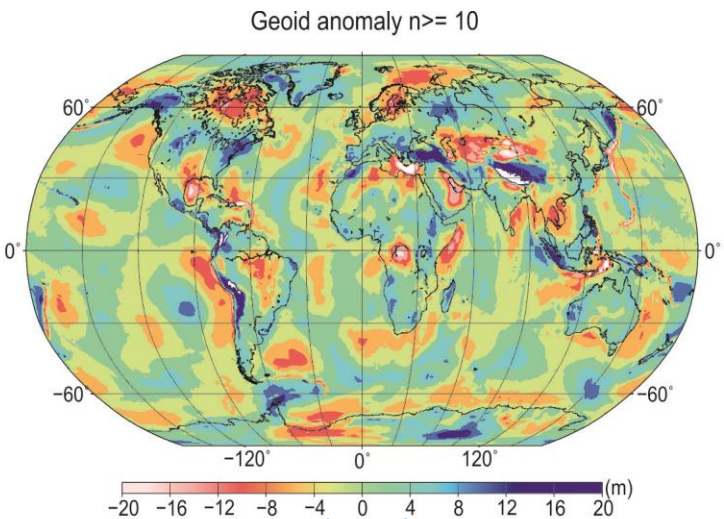
(Celli & Lebedev, unpublished data.)

- ✓ **Surface wave phase velocity anomaly maps.**
- ✓ **Sensitive to temperature composition in the crust and uppermost mantle**

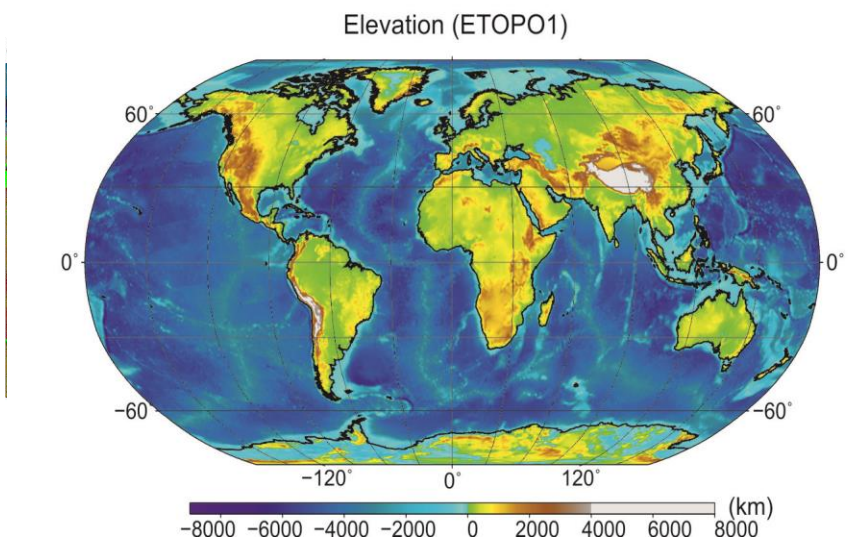
Earth simulator: data



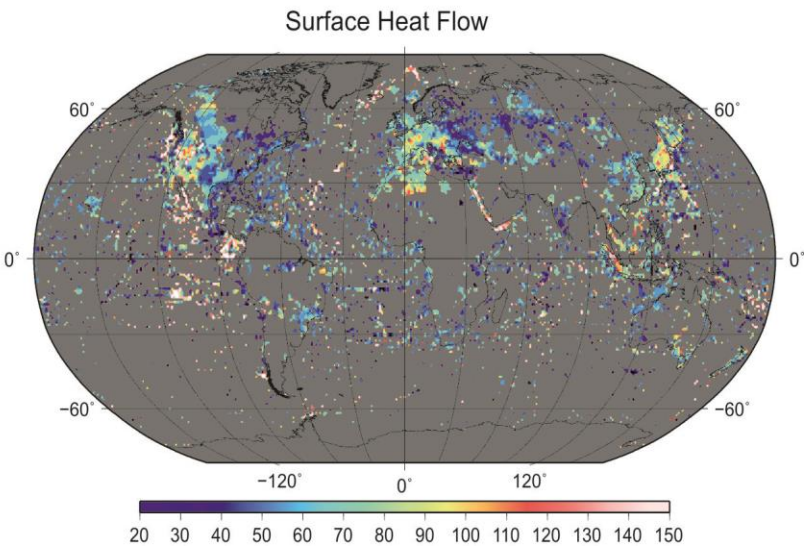
(Schaeffer & Lebedev, 2013, 2015; Celli & Lebedev, in prep.)



Geoid anomalies (GRF): GOCE & EGM2008



Elevation (GRF) ETOPO2, GEBCO, SRTM.

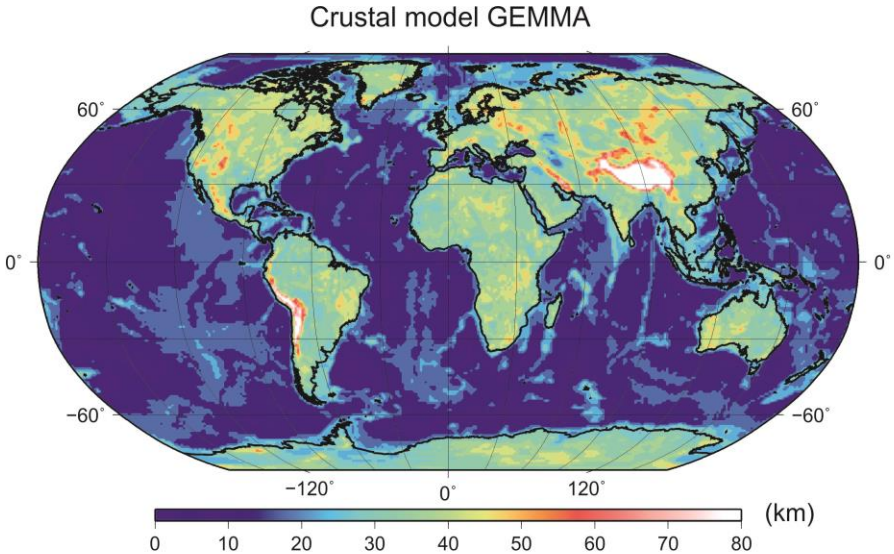


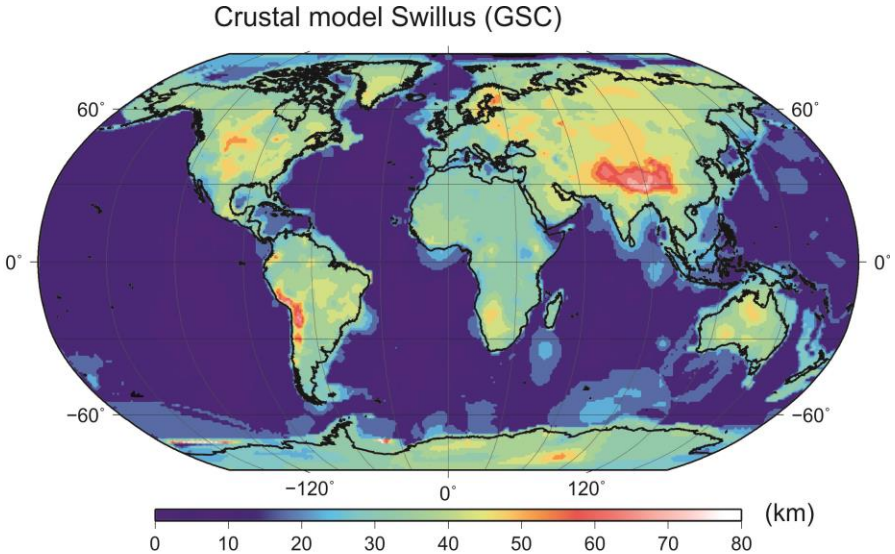
Surface heat flow (GRF): International Heat Flow Commission, IASPEI

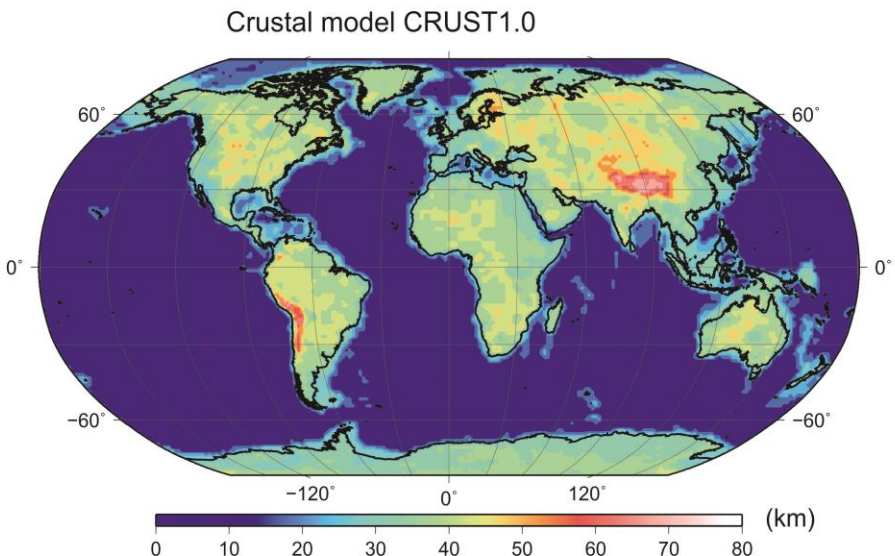
Earth simulator: 1D inversion

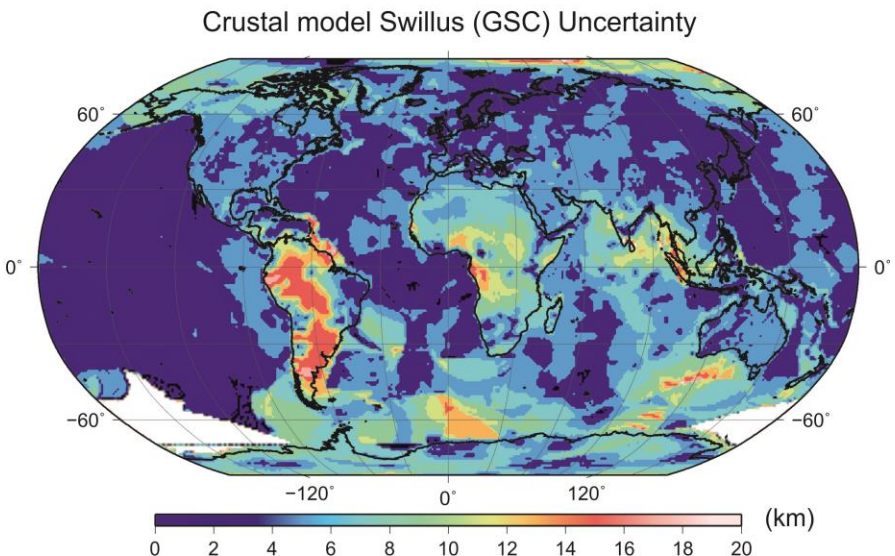
WINTERC

Include Moho depth (interaction with CAU)



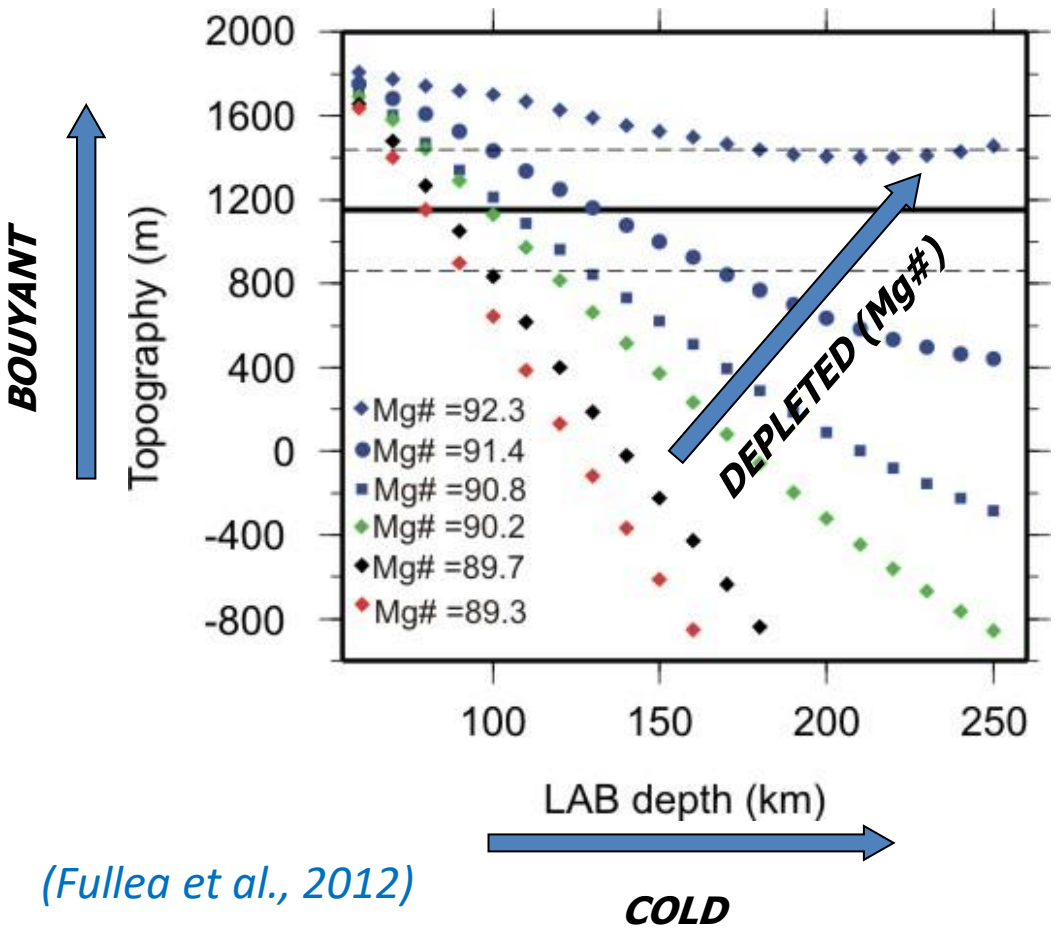




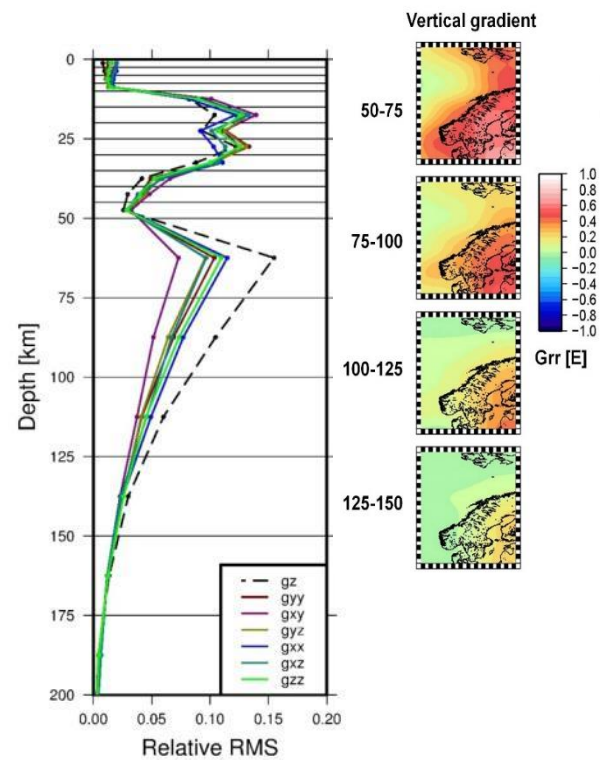


WP3220: 3D Earth simulator

Density=f(Temperature, Composition)



(Fullea et al., 2012)



Relative signal for lithospheric depth slices – North East Atlantic region

- ***Density is significantly affected by composition***
- ***Gravity data is very sensitive to crustal structure***