wege entstehen, indem wir sie gehen
paths emerge in that we walk them

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Three dimensional reconstruction of the atmospheric ENSO signal

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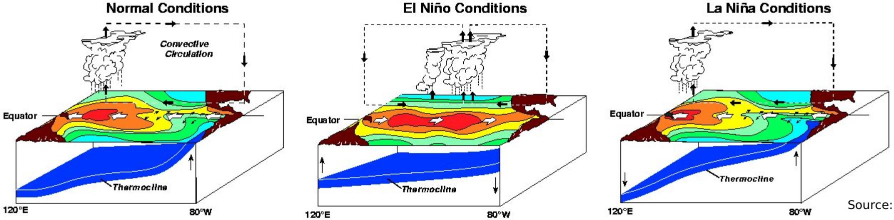
El Niño-Southern Oscillation

- Atmosphere-ocean interaction
- **El Niño/La Niña**: surface temperature variations in the tropical eastern Pacific Ocean
  Southern Oscillation: surface air pressure variations in the tropical western Pacific
- interannual variations of convection, atmospheric temperature and circulation
- occurs every 2 to 7 years
- lasts a couple of months to two years



Source: NOAA

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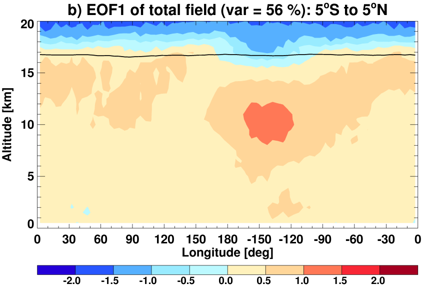
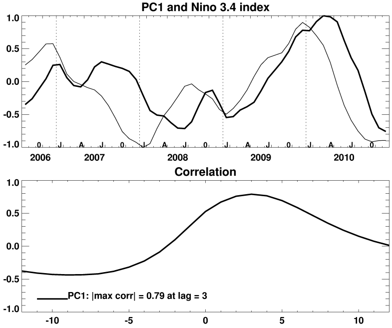
Radio occultation data

- temperature profiles and total column water vapor
- from CHAMP, GRACE-A, and COSMIC
- from August 2006 to December 2010
- temporal resolution: monthly means
- initial horizontal resolution: $5^\circ \times 5^\circ$
- vertical resolution: 100 m
- use data up to 20 km
- subtract mean annual cycle (Jan 2007 to Dec 2010)
- smooth short-period fluctuations with a 1-2-1 filter at every gridpoint

EOF analysis of the total field



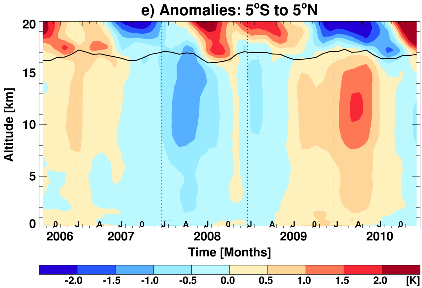


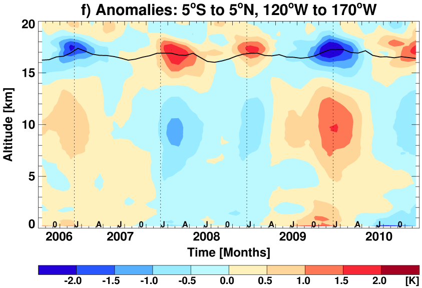
PC1 time series is highly correlated with the Nino 3.4 index ($r = 0.79$)

EOF1 indicates a natural split into zonally symmetric and asymmetric ENSO variability;

$\rightarrow$ Decompose the anomaly field into a **zonal mean component** and into deviations from the zonal mean **(eddy component)**

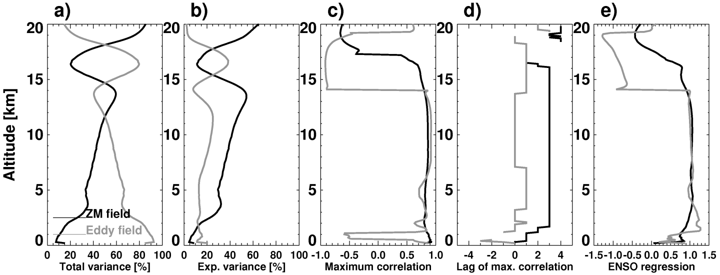
Temperature anomaly fields





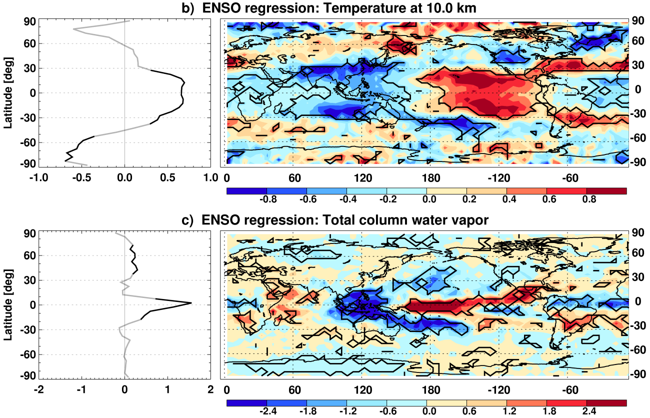
- **El Niño**: 2006/2007, 2009/2010
- **La Niña**: 2007/2008, 2008/2009, 2010/2011
- **Quasi-biennial oscillation (QBO)**: quasi-periodic oscillation in the tropical stratosphere

→ Apply an EOF analysis at every altitude level separately to the zonal-mean and eddy fields



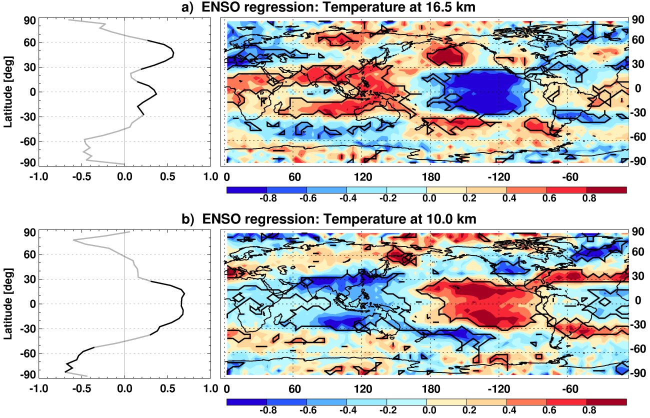
- **Zonal mean EOF1** accounts for the largest amount of variance (except from 16 km to 18 km altitude)
- high positive correlation with N3.4 index up to the tropopause
- lag between the zonal mean PC1 and the N3.4 index: 3 months
- **Eddy EOF1** explains most variance between 16 km and 18 km altitude
- high positive correlation with N3.4 index up to 14 km, negative above
- eddy PC1 is in phase with the N3.4 index

Regression maps



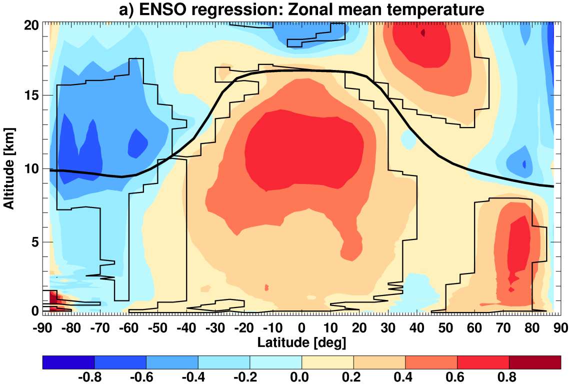
Zonal mean: Exchange of fluxes at the atmosphere-ocean interface and atmosphere energy loss to space and to mid latitudes (Su et al. 2005)
Eddy: Kelvin waves yield the tropical tropophere to respond rapidly to a anomalous diabatic heating (e.g., Heckley and Gill 1984; Ryu et al. 2007)

Regression maps



Zonal mean: positive ENSO signal at low latitudes, at high latitudes at 10 km, and at mid northern latitudes at 16.5 km
Eddy: Tropospheric heating yields a shallow layer of cooling at the tropopause level (Holloway and Neelin 2007)

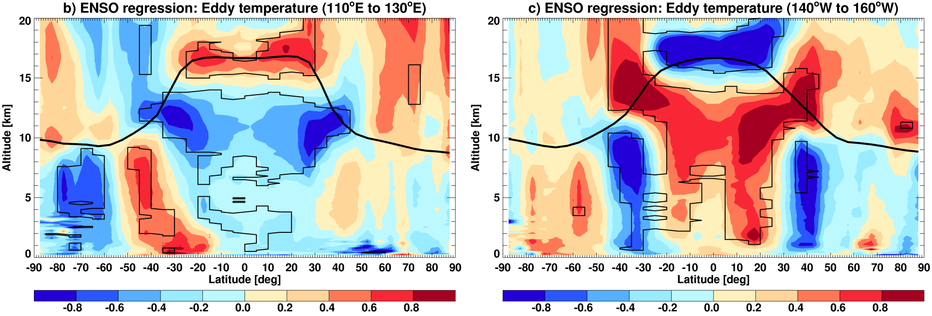
Multiple regression



Zonal mean:

- Positive zonal mean ENSO signal extends to the tropopause at low and mid latitudes
- Negative ENSO response at stratospheric levels. . .
- but strong positive lower stratospheric signal at northern mid latitudes

Multiple regression



Eddy:

- significant negative/positive ENSO response equatorwards of 25° latitude up to 14 km
- positive/negative ENSO response above
- in tropospheric extratropics up to 45°, the ENSO signal is out-of-phase with the low latitude signal

Summary

- **RO data** clearly capture the **ENSO signal** in the troposphere and lower stratosphere
- the ENSO signal consists of a distinctive zonal-mean component and deviations from the zonal mean (eddy component)
- **Zonal-mean component**:
  - lags the surface ENSO signal by 3 months
  - warm tropospheric, cold stratospheric zonal-mean temperatures
  - node of these positive and negative correlations occurs around the tropopause
- **Eddy component**:
  - ENSO signal response rapidly to anomalous diabatic heating
  - atmospheric eddy ENSO signal features an east-west dipole at low latitudes
  - the vertical node to a reversed east-west dipole occurs at approximately 14 km
  - at mid latitudes, significant ENSO signals are out-of-phase with the low latitude signal