A multi-diagnostic intercomparison of tropical width and jet timeseries using meteorological reanalyses and satellite observations

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Abstract

Recent evidence suggests that changes have occurred in the position of the "tropical belt" as defined by various aspects of the Hadley cell, jets, and tropopause height. Previously published observational estimates of tropical widening cover a wide range from around 0.2 – 3 degrees per decade, and there is some indication that these rates of tropical expansion are greater than those predicted by climate models. In this presentation, we investigate the extent to which the differences among tropical widening estimates can be attributed to the different methodologies for tropical edge definition and different datasets. We consider both previously published and new objective tropical width definitions based on outgoing longwave radiation from satellite measurements, and Hadley cell, wind, and tropopause-based estimates from multiple meteorological reanalyses. Tropical widening estimates reveal continued tropical widening in some metrics, but not others, with fairly consistent results across the different reanalyses for any given metric. However, significant differences occur both between and among the various classes of tropical width metrics. Within a certain class of metrics, significant differences can be due to the aliasing of global-mean change in the quantities of interest to tropical width change, and sensitivities related to arbitrary threshold choices. Differences are also found on seasonal and hemispheric scales, and these differences are discussed in the context of the different physics of the general circulation encapsulated by the various metrics.

Introduction

• The "tropical belt" is loosely defined as the region equatorward of the subtropical jet, the edges of which form the boundary between the dry subtropics and midlatitudes.

• The edges of the tropical belt, and jets, have been diagnosed in a multitude of ways using observations, meteorological reanalyses, and climate models (see Figure 1 below)

• Tropical belt widening has been identified in observations and reanalyses

• Previous estimate of widening are ~ 1˚ - 2˚ decade^{-1} since 1979

• Models forced with GHG emissions and ozone depletion produce Hadley cell widening, but at slower rates than in observations (Johanson and Fu, J. Clim, 2009).

• 21[st] century Hadley cell widening ~ 0.1˚ - 0.2˚ decade^{-1}

Tropical belt metrics: categorization

• Tropical edge diagnostics can be broadly categorized based on the ***physical property*** and ***methodology*** by which they are computed

• ***Physical properties*** used here are:
  - Tropopause height (z_{TP})
  - u, v winds
  - Outgoing Longwave Radiation (OLR)
  - Precipitation, Evaporation (P, E)

• ***Methodologies*** are shown in table below, and examples are shown in Fig 1.

Tropical edge identification methodologies

Type	Description	Advantages	Disadvantages	Interpolated?	Constrained to grid box?	Examples	References
Absolute / Subjective threshold	Latitude at which quantity reaches a threshold as it changes from it's tropical to extratropical value	Conceptually simple	Requires arbitrary threshold, sensitive to global mean distribution and changes	Yes	No	z_{tp}=15 km, OLR=250 W m^{-2}	Seidel and Randel, 2007; Hu and Fu, 2007
Relative (Δ) / Objective threshold	Latitude at which quantity reaches a threshold change from its peak or tropical mean value, or lat at which it reaches a zero-crossing	Not sensitive to global mean, or global mean changes	Still involves a subjective threshold	Yes	No	Δz_{tp}=1.5 km	Davis and Rosenlof, in press
Mean	1st moment of latitudinal distribution of quantity of interest over a specified range	Includes information over a range of latitudes	More complex calculation, interpretation	No	No	$u_{100-400}$	Archer and Caldeira, 2008
Max (or min)	Latitude at which quantity reaches a maximum or minimum	Conceptually simple, often physically meaningful	Problems identifying weak peaks	No	Yes	P-E=0, Ψ_{500}=0	Hu and Fu, 2007,

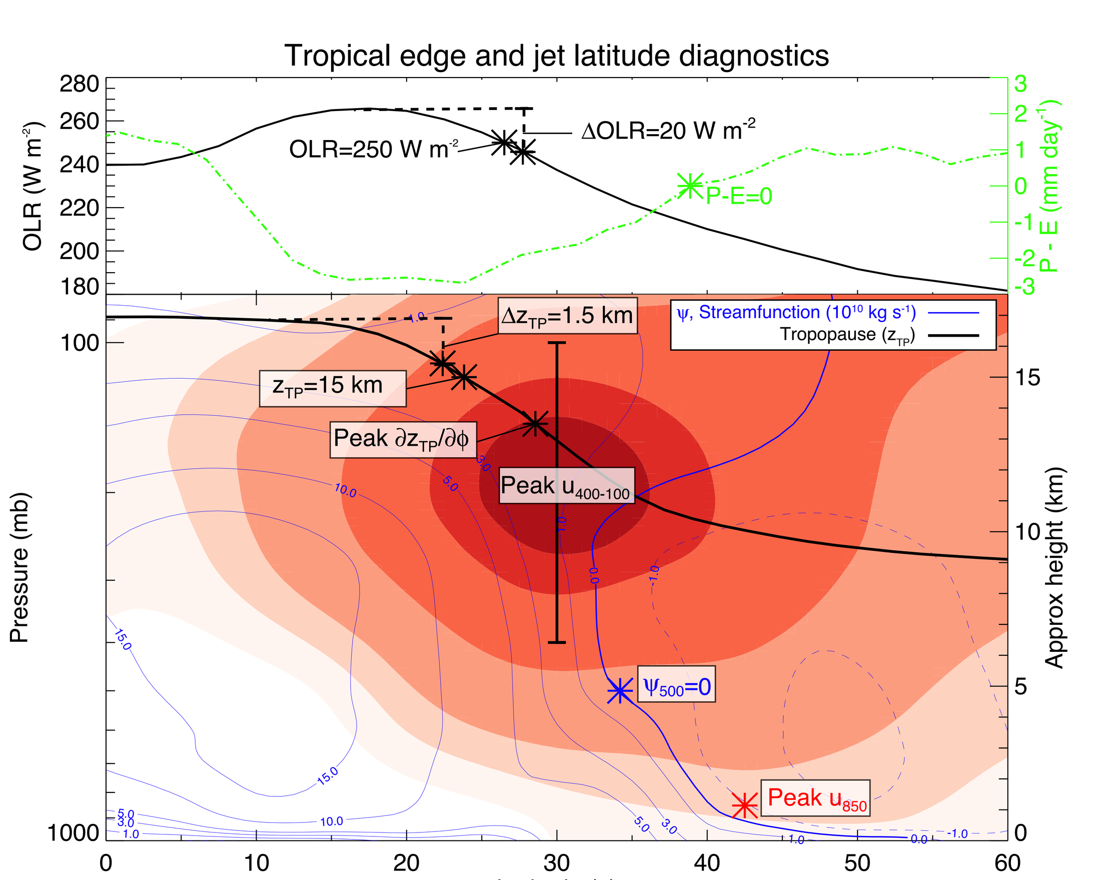

Figure 1. Tropical belt diagnostics for January 2008 from the NCEP/NCAR reanalysis. Symbols denote the latitudes of the tropical belt edges from several diagnostics that have been used in the literature (see figure legend and text for descriptions).

Tropical belt metrics: details

• Reanalysis data from NCEP/NCAR (R1), NCEP CFSR, ERA-40, ERA-interim, and JRA

• OLR from datasets used in Hu and Fu, 2007, and from NCEP interpolated OLR dataset (http://www.esrl.noaa.gov/psd/data/gridded/data.interp_OLR.html)

• Latitudes calculated for each hemisphere on zonal-mean, monthly-mean fields
  - Tropopause from 6-hourly model level temperatures, before monthly average

Metric Definitions:

• z_{TP} = 15 km - Most equatorward latitude where tropopause equals 15 km

• Δz_{TP} = 1.5 km - Latitude where tropopause falls to 1.5 km below 15°S-15°N average

• u_{850} - Mean (or max) zonal wind at 850 hPa, averaged 15˚ - 70˚

• $u_{400-100}$ - Mean (or max) mass-weighted wind (400-100 hPa), averaged 15˚ - 70˚

• ψ_{500}=0 - Zero-crossing of mean meridional streamfunction at 500 hPa

• P-E=0 - First zero-crossing of precip-evaporation poleward of subtropical minimum

• OLR = 250 W m^{-2} - Latitude poleward of subtropical max where OLR=250 W m^{-2}

• ΔOLR = 20 W m^{-2} - Latitude where OLR 20 W m^{-2} less than subtropical max

Tropical belt: seasonal cycle

• The seasonal cycle and interannual variability in tropical belt and jet latitudes depend on both the physical quantity and methodology used

• Differences exist between the hemispheres, with SH amplitudes generally < than NH

• For NCEP and ECMWF reanalyses, both older and newer reanalyses are shown.

• Some differences can be seen, particularly in the ψ_{500}=0 and P-E=0

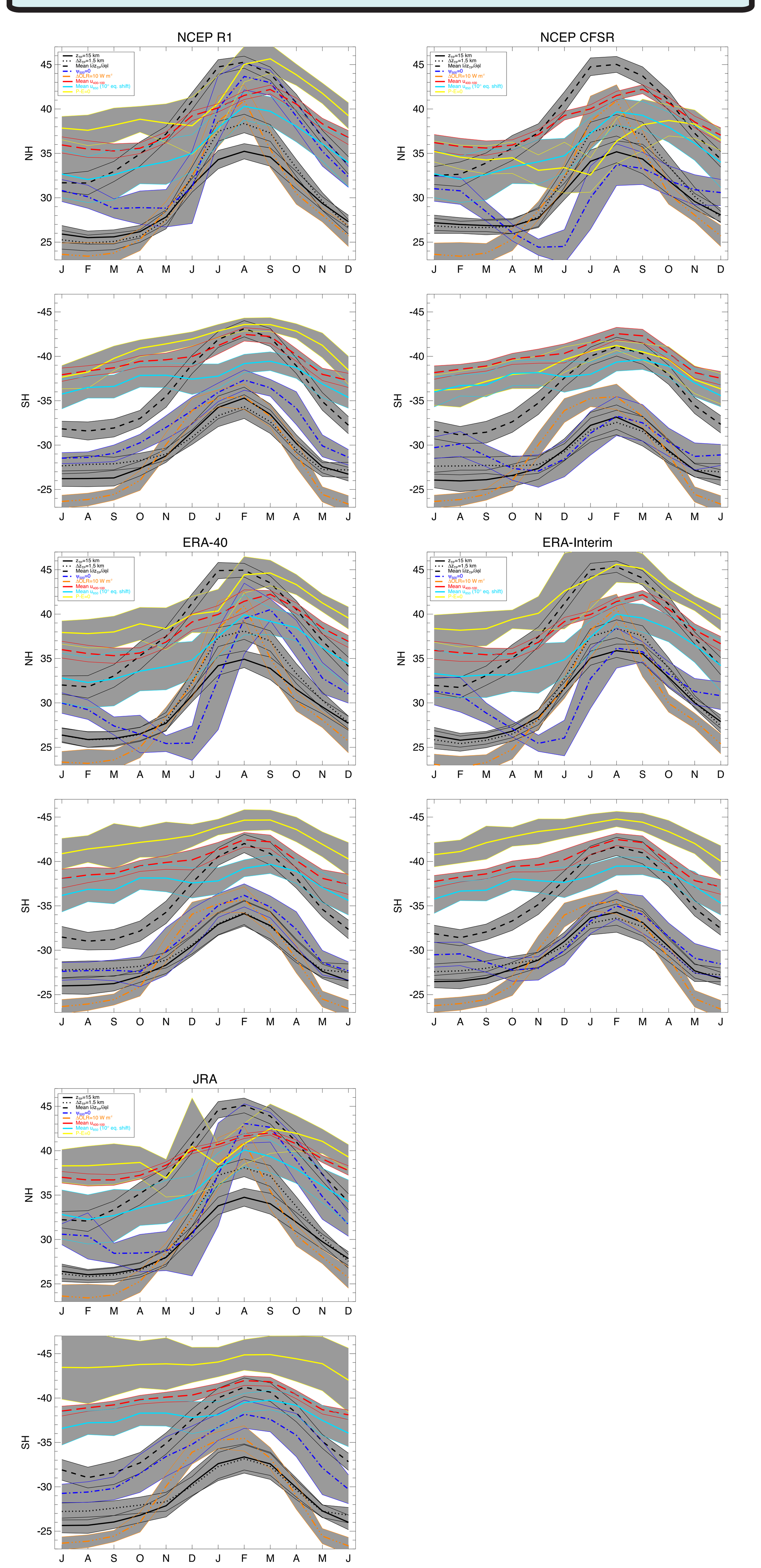

Figure 2. Seasonal cycle of some tropical belt metrics from each reanalysis. The gray shaded areas are the 1σ standard deviations of the latitude for the given metric at each month, representing interannual variability in tropical belt/jet position.

Tropical belt and jet timeseries

• Timeseries from 1979 - 2009 are shown below

• For tropopause height and OLR, trends are larger using subjective threshold metrics, compared to other types of metrics (see discussion below).

• As expected, metrics based on the mean contain less noise than those based on simple extrema.

• For a given type of metric, good agreement is found among the reanalyses, with some notable exceptions:
  - ψ_{500} = 0: Edge latitudes are upwards to ~5˚ different in NH
  - P-E=0 : Good agreement in NH, not in SH. Discontinuity in JRA in 1986 due to SSM-I PW introduction.
  - OLR = 250 W m^{-2}: See below for further discussion

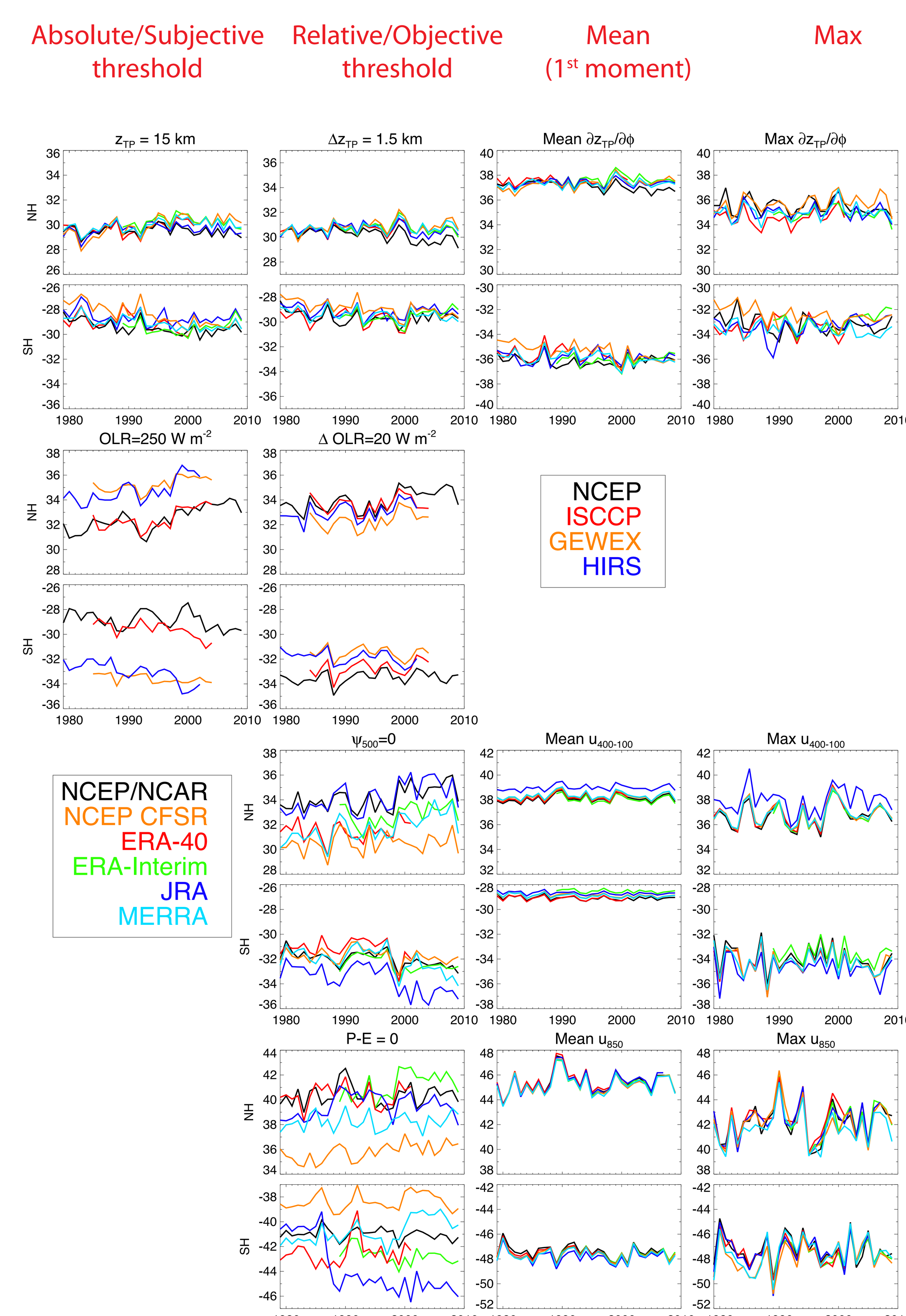

Figure 3. Tropical belt and jet timeseries from different reanalyses and satellite OLR data sets

OLR trends:

• The difference in absolute latitude of the OLR = 250 W m^{-2} metric is due to the slightly different absolute values of OLR in the different data sets

• Trend differences between OLR = 250 W m^{-2} and ΔOLR = 20 W m^{-2} metrics due to large scale trends in some OLR datasets

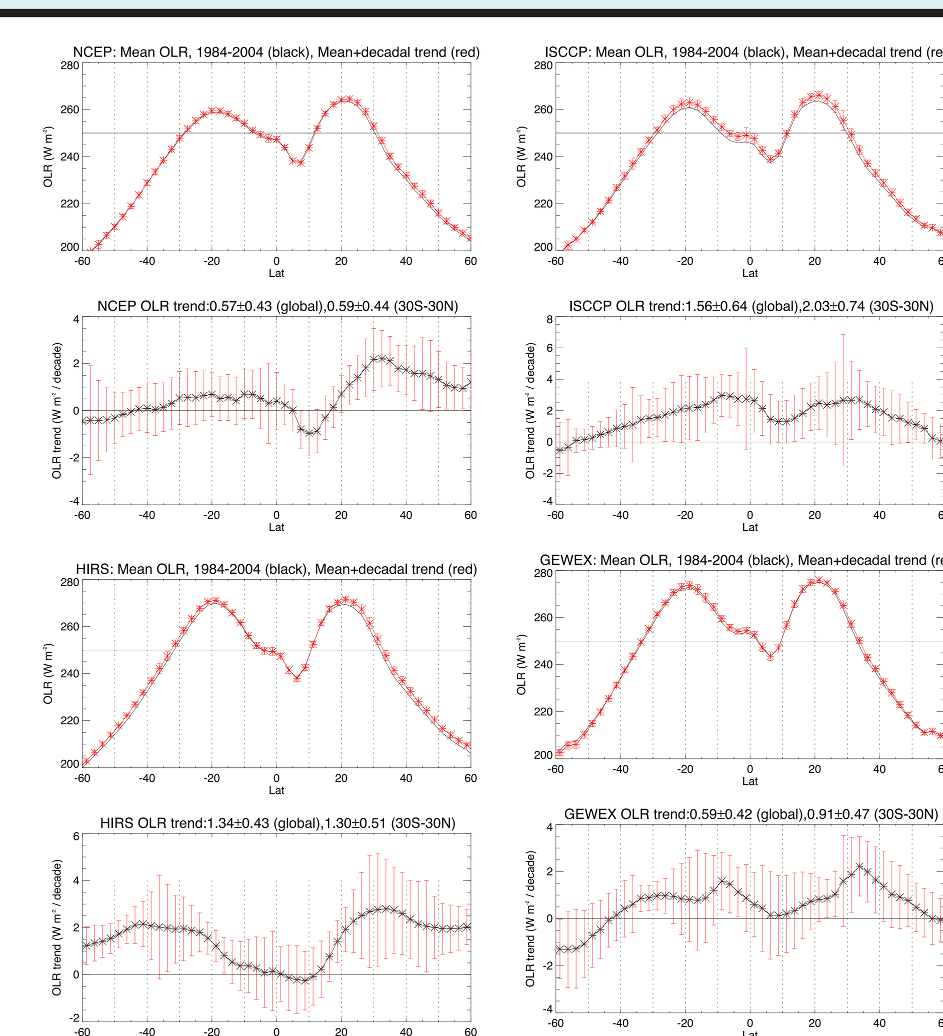

Figure 4. Trends in zonal-mean OLR from four datasets, with 95% confidence interval on the trend shown.

Tropical width trends

• Trends in the tropical width from 1979 - 2009 are shown below, broken up by hemisphere (and total)

• Trends in ERA-interim, ERA-40, not shown, because they don't cover 1979-2009

• Uncertainties in "Mean" trends always smaller than for "Max" for a given metric type
  -> Implies better ability to detect change in these types of metrics

• Relative threshold metrics have smaller trends than absolute

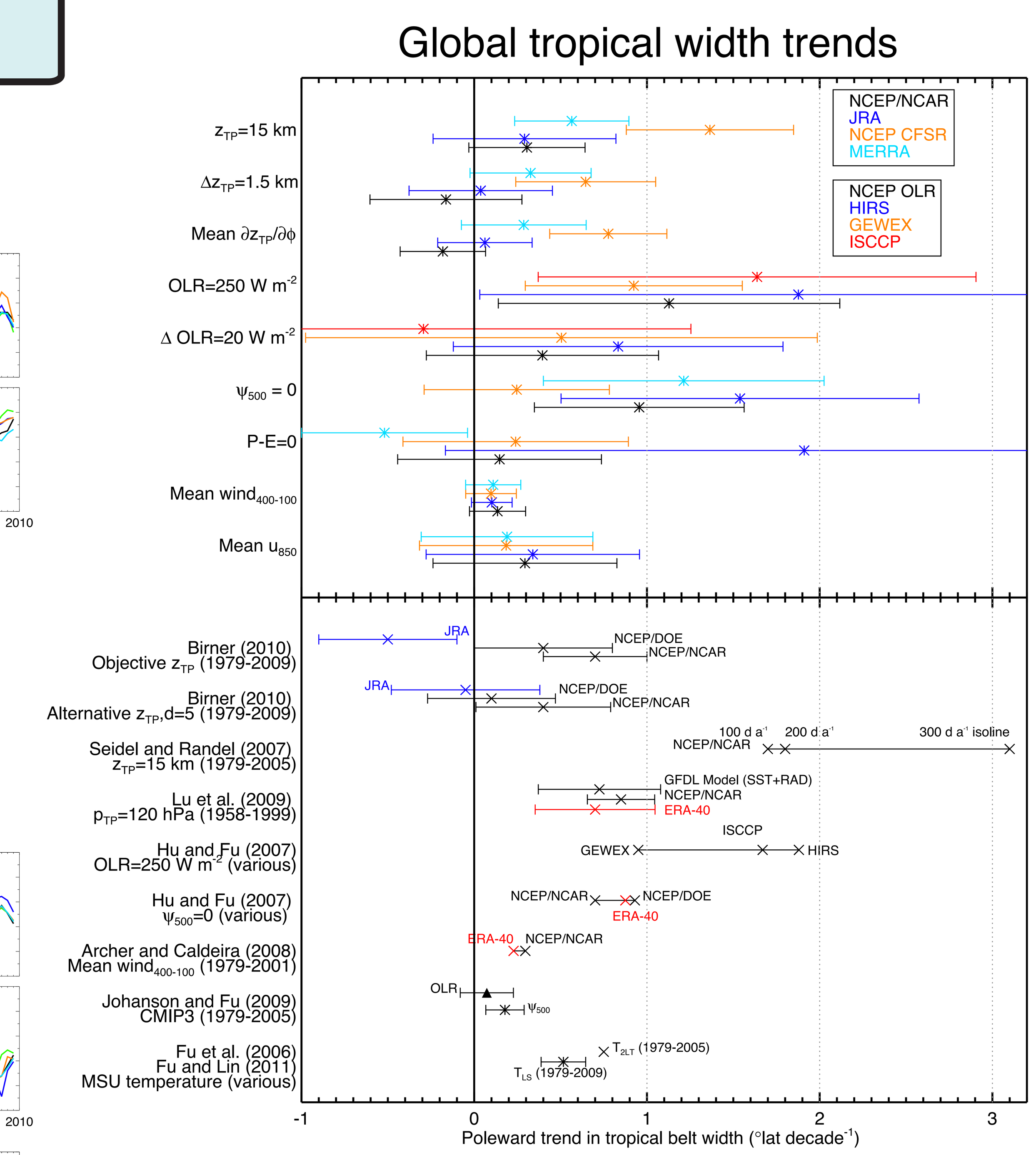

Figure 5. Trend summary plot for tropical widening and jet metrics. Horizontal error bars are 95% confidence interval on the trend. The top panel shows trends from this study, and the bottom panel shows trends from previous work.

Conclusions

• Although conceptually simple, tropical edge definitions based on absolute subjective threshold values have several potential drawbacks:
  1. Widening trends will be induced if large-scale trends exist in the physical quantity of interest (e.g., tropopause height, OLR).
  2. Similarly, absolute edge latitude is a function of the global mean value, so different datasets may yield different latitudes, even when the shapes are very similar (e.g., OLR).

• "Mean" metrics based on the 1[st] moment of the distribution contain less interannual variability because they incorporate more information into the latitude calculation, and this leads to better ability to detect trends.
  - Better noise characteristics may yield more robust detection over shorter periods of time in both model experiments and data

• For a given metric, agreement among the reanalyes varies:
  1. CFSR tropopause widening >> NCEP/NCAR and JRA
  2. Large disagreement in Hadley cell metrics
  3. JRA much different in P-E trends, but primarily due to jump in SH in 1986
  3. Good agreement in wind-based metrics

• In terms of global trends, this study shows statistically insignificant trends, except
  1. CFSR tropopause (disagreement with others)
  3. ψ_{500} trends are positive (except CFSR)

• Differences in trends values between this study and previous studies primarily due to
  1. Use of objective metrics
  2. Extended time period of trend calculation

• Hemispheric differences in widening trends:
  1. Tropopause widening in SH
  2. Significant OLR widening in NH, not in SH

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