Evaluation of the Stratosphere in the CORe dataset

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(evaluation is not complete…updates are ongoing)

Data

- CORe
- Internal Reanalyses
  - NCEP-NCAR Reanalysis 1, NCEP-NCAR Reanalysis 2, CFSR
- External Reanalyses
  - ERA-5, JRA-55, MERRA-2
- Other datasets
  - CPC/AMSU Stratospheric Temperature and Heights analysis
- Period of Analysis
  - In most cases, the period 1979-2020 was used, particularly for seasonal cycle/mean statistics
    - This was the period with the most overlap between the reanalyses
  - In many of the time series plots, each reanalysis extends back to the beginning of its record
- Most analysis uses zonal means → majority of key stratospheric features can be captured this way
- Note: I tend to use “biases” and “differences” interchangeably. Not sure if this is the correct terminology

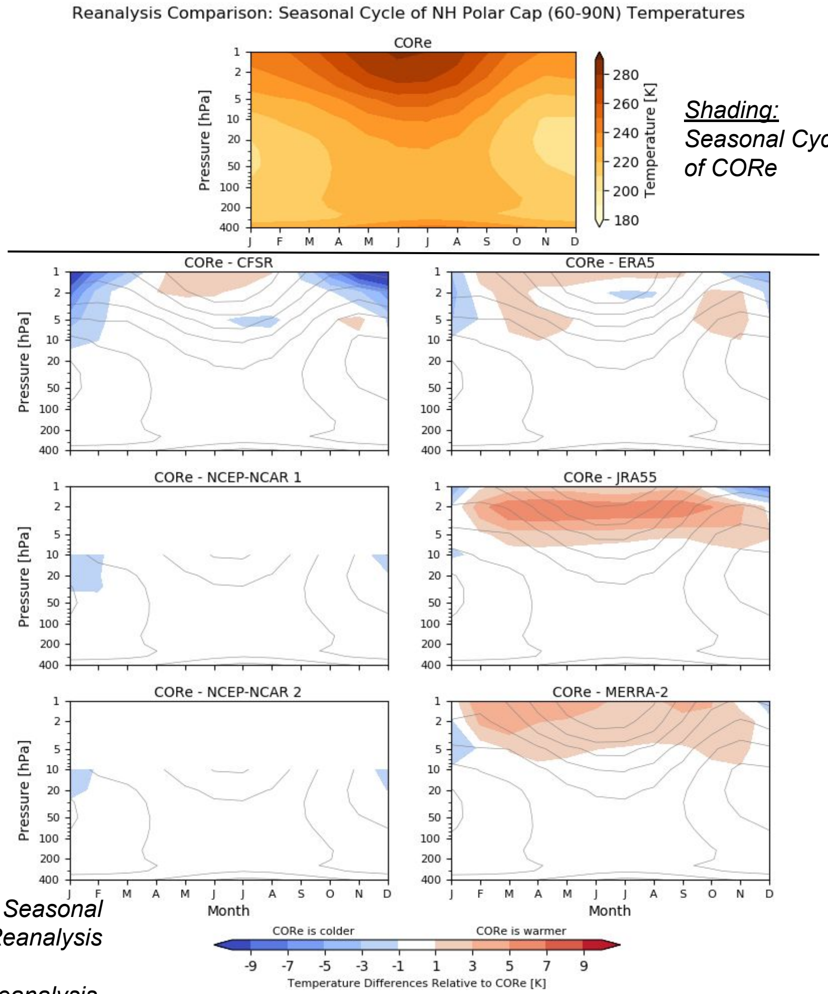
Analysis of Monthly Means

This is a work in progress…will update as further analysis is completed

Temperature

Seasonal Cycle of NH Polar Cap Temperatures (1979-2020)

- Period: 1979-2020 → so that CFSR, MERRA-2 and NCEP-2 could be included
- Note pressure level extends down to 400-hPa
- Strongest differences occur in upper stratosphere (<10-hPa)
- Relative to other reanalyses, CORe a cold bias during the boreal winter
  - Boreal winter cold bias is strongest relative to CFSR
- COre exhibits a warm for most months, except for
  - Warm biases are strongest relative to JRA55 (and MERRA2 to a lesser extent)
- Biases above 10hPa are typically weakest relative to ERA5

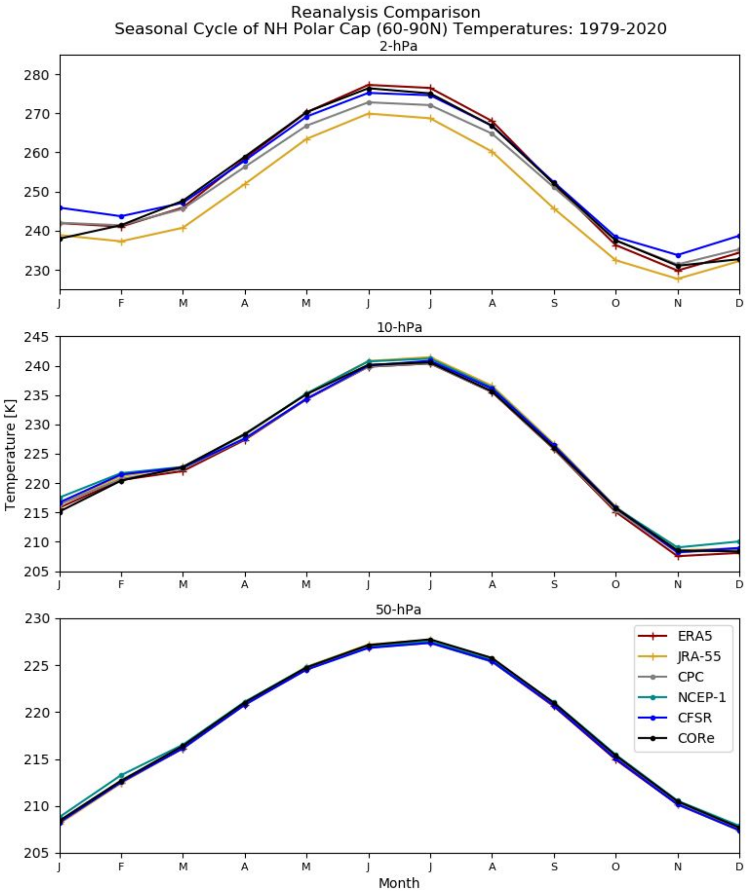


Shading: Seasonal Cycle of CORe

Contours: Seasonal Cycle of Reanalysis
Shading: CORe - Reanalysis

Seasonal Cycle at NH Stratospheric Polar Cap (1979-2020)

- Note MERRA-2 and NCEP-2 are not analyzed
  - Too many lines→ cluttered figure; MERRA-2 results similar to JRA/ERA; NCEP-2 similar to NCEP-1
  - Added CPC/AMSU stratospheric temperature analysis
- CORe values typically fall within the range of other reanalyses
- 2-hPa: differences are strongest
  - CORe colder in winter months (particular December-January)
  - JRA-55 is consistently colder throughout all months
- 10/50-hPa: Agreement increases with with pressure



Comparison of NH Stratospheric Polar Cap Seasonal Cycle Periods

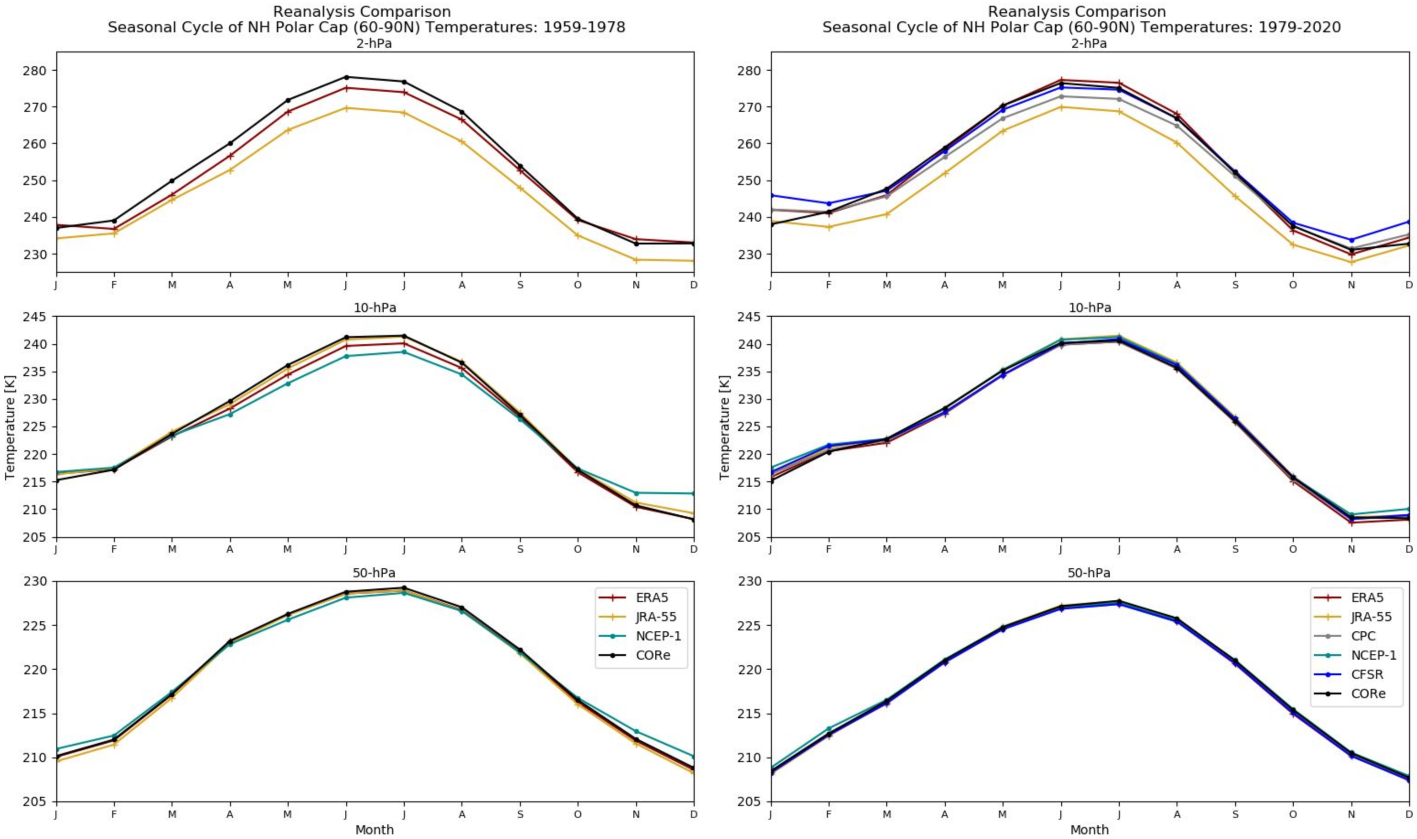
Purpose: Examine if seasonal cycles exhibit noticeable differences prior to 1979-2020 period.

Comparison period: 1959-1978 → 4 re-analyses overlapped during this period

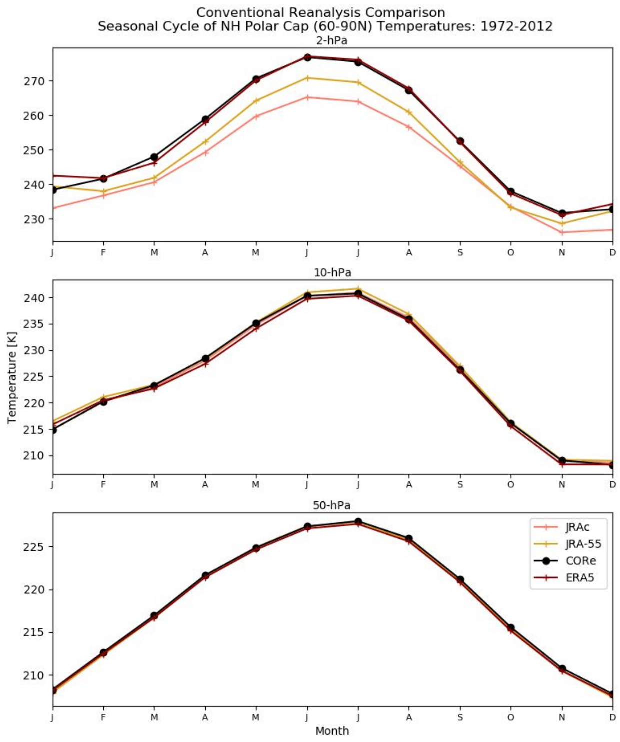
Overall, seasonal cycles are slightly warmer

1959-1978: JRA remains consistently colder than other reanalyses

Agreement not as strong at 10-hPa but overall still good

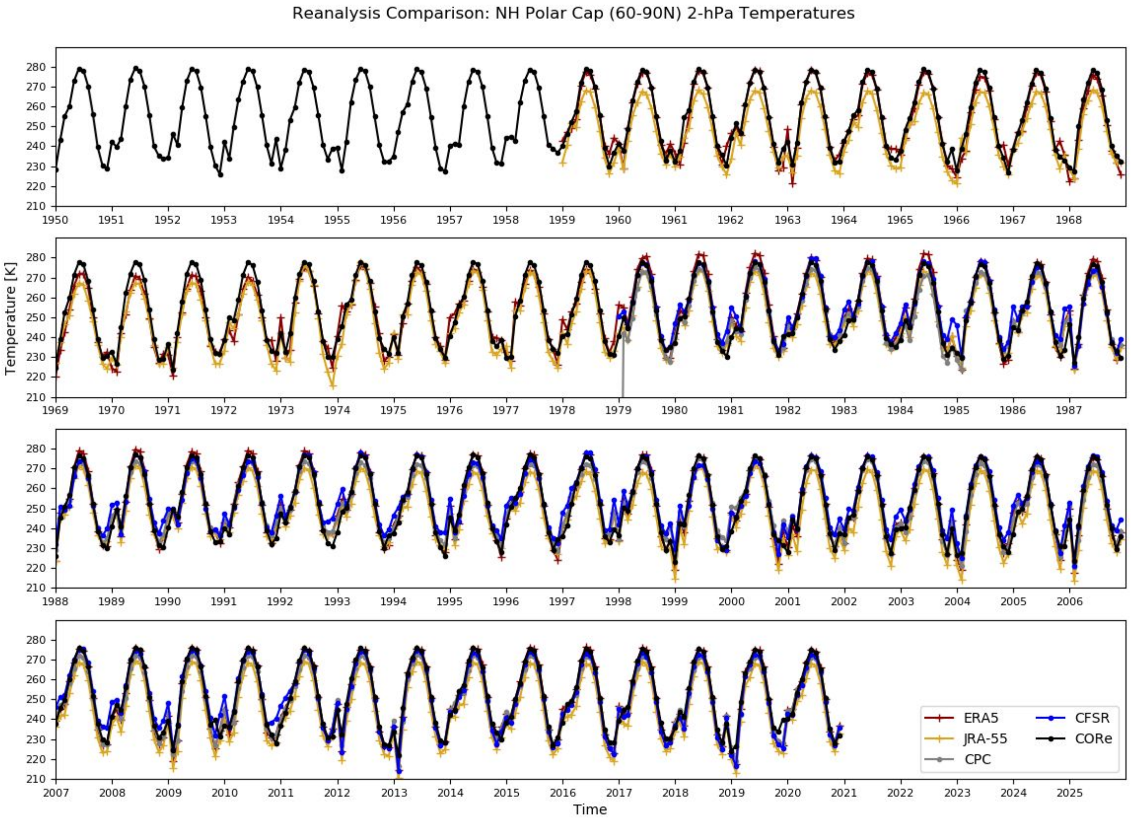


Comparison of NH Stratospheric Polar Cap Seasonal Cycle with JRAc



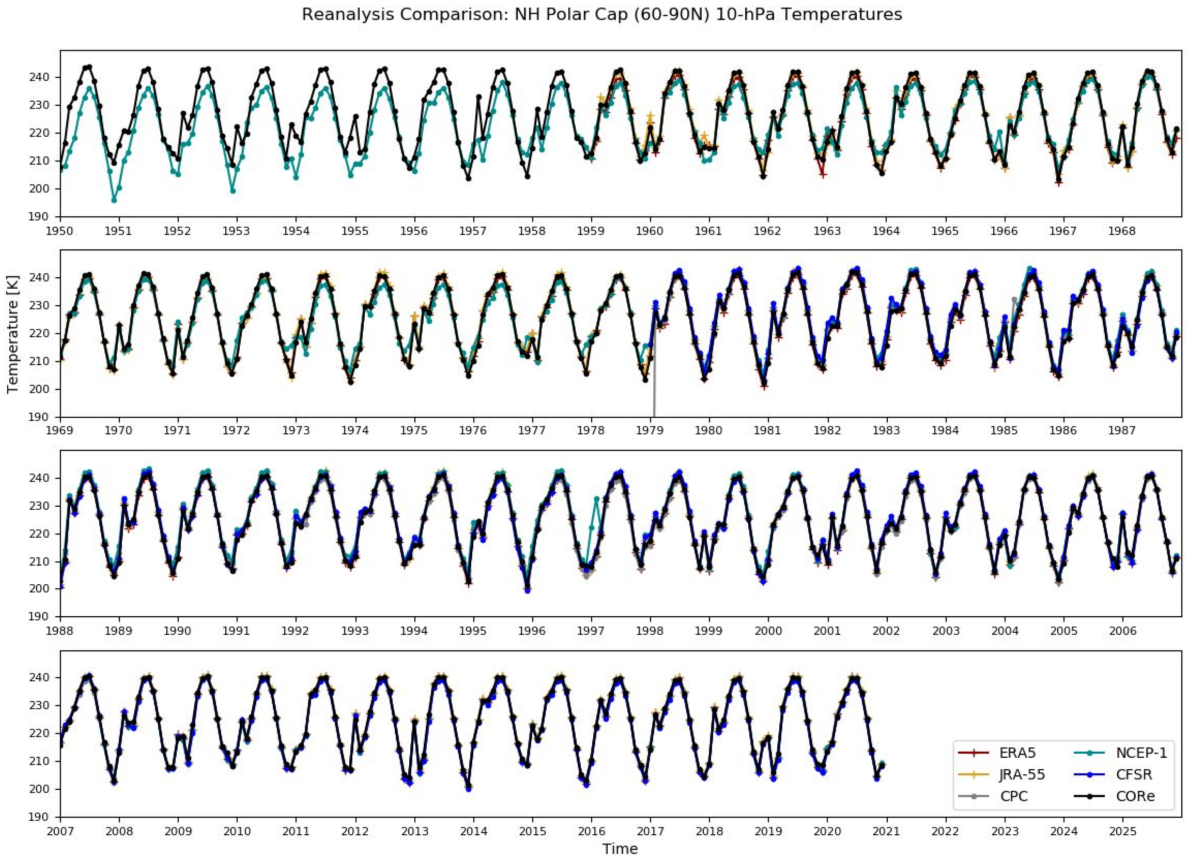
Time Series of 2-hPa NH Polar Cap Temperatures

- Purpose: Examine whether differences evident in the seasonal cycle are confined to specific time period or are consistent across 1979-2020
- CORe typically falls within in the range of other reanalysis temperature values
- CORe seems more consistent with ERA/JRA than CFSR which tends to be warmer than the other reanalyses during the winter months
- JRA tends to be colder than others



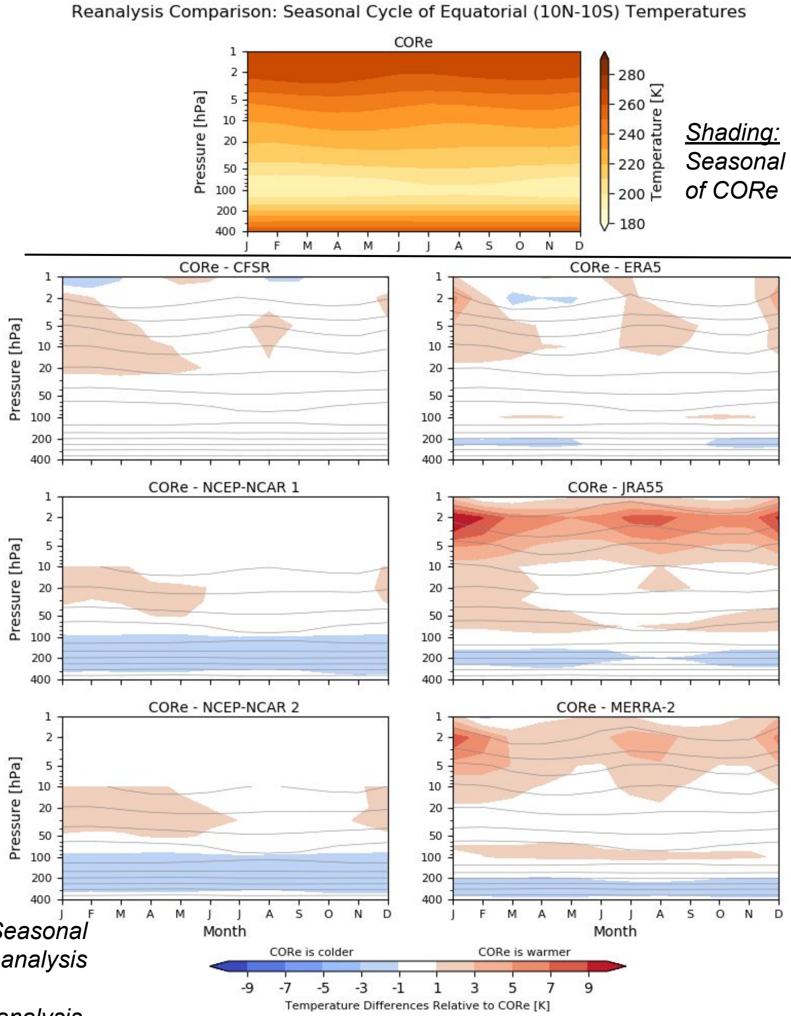
Time Series of 10-hPa NH Polar Cap Temperatures

- By 10-hPa, the differences between the re-analyses are considerably smaller
- Particularly after 1979



Seasonal Cycle of Equatorial Temperatures (1979-2020)

- Note pressure level extends down to 400-hPa
- CORe is generally warmer in upper stratosphere (above 10-hPa)
  - Strongest in JRA-55/MERRA-2; consistent with the typically colder temperatures of JRA-55
  - Weakest in CFSR/ERA5
- Slight cold bias in lower stratosphere/upper troposphere (100-400-hPa) except for CFSR and ERA5



Shading: Seasonal Cycle of CORe

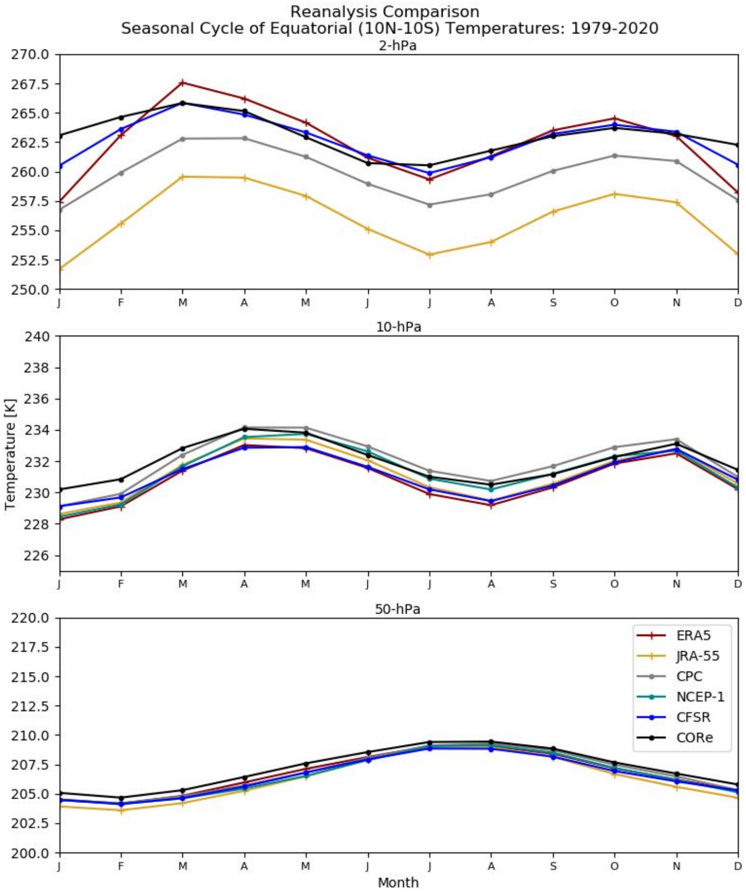
Contours: Seasonal Cycle of Reanalysis
Shading: CORe - Reanalysis

Seasonal Cycle Equatorial Region (1979-2020)

- Note MERRA-2 and NCEP-2 are not analyzed
  - Too many lines→ cluttered figure; MERRA-2 results similar to JRA/ERA; NCEP-2 similar to NCEP-1
  - Added CPC/AMSU stratospheric temperature analysis

- 2-hPa: Largest range of values between re-analyses
  - CORe generally consistent with ERA-5 and CFSR
  - JRA-55 consistently colder than other reanalyses

- 10/50-hPa: Agreement improves with pressure



Comparison of Equatorial Stratospheric Seasonal Cycle Periods

Purpose: Examine if seasonal cycles exhibit noticeable differences prior to 1979-2020 period.

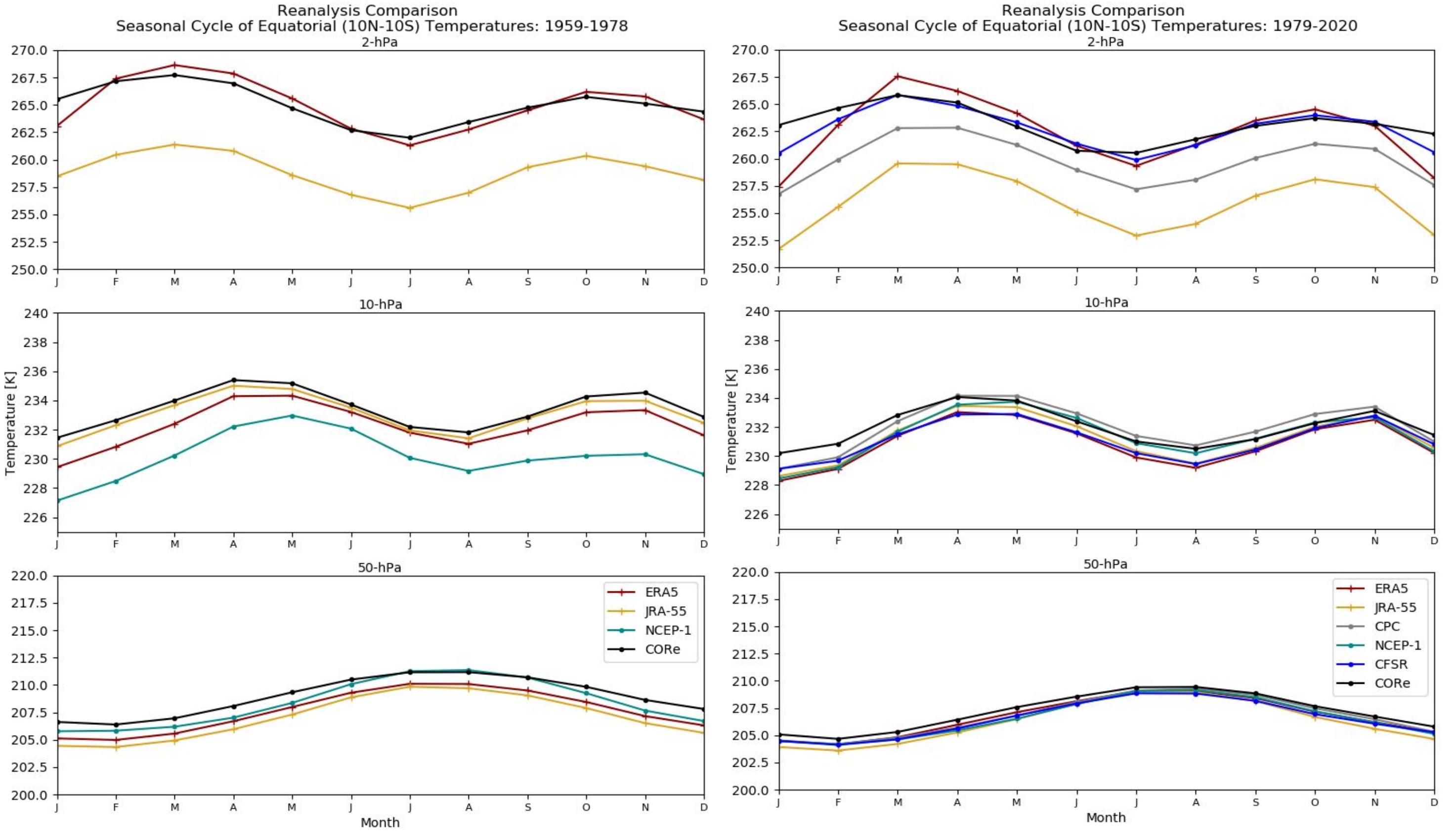
Comparison period: 1959-1978 → 4 re-analyses overlapped during this period

Overall, seasonal cycles are slightly warmer; particularly JRA

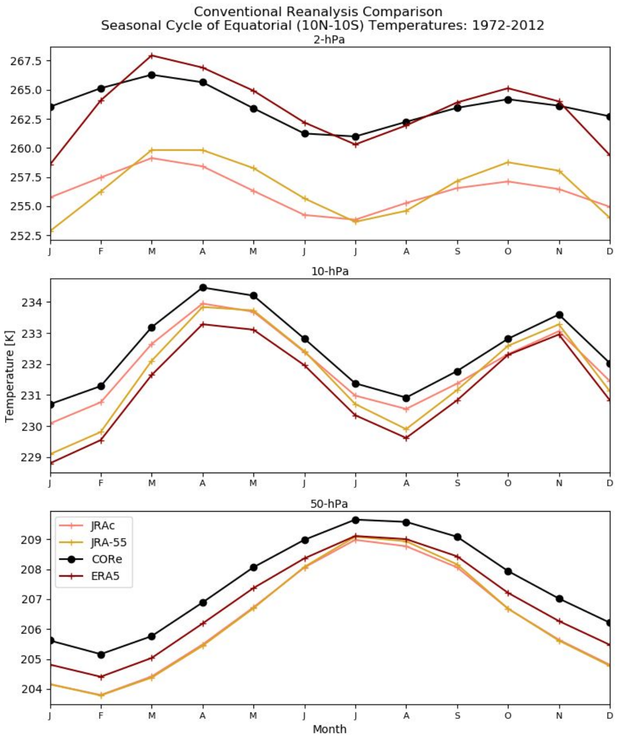
1959-1978: JRA remains consistently colder than other reanalyses at 2-hPa

1959-1978: NCEP-1 colder than others at 10-hPa

Agreement not as strong at 10-hPa but reasonable, more so at 50-hPa



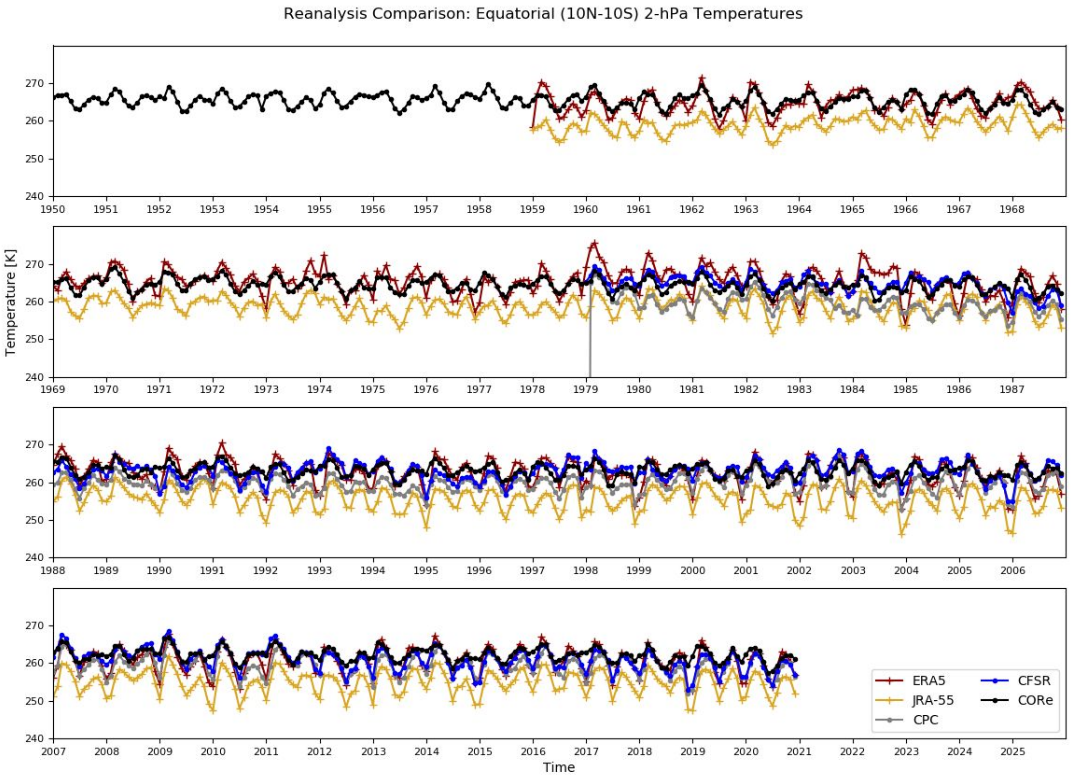
Comparison of Equatorial Stratospheric Polar Cap Seasonal Cycle with JRAc



Time Series of 2-hPa Equatorial Temperatures

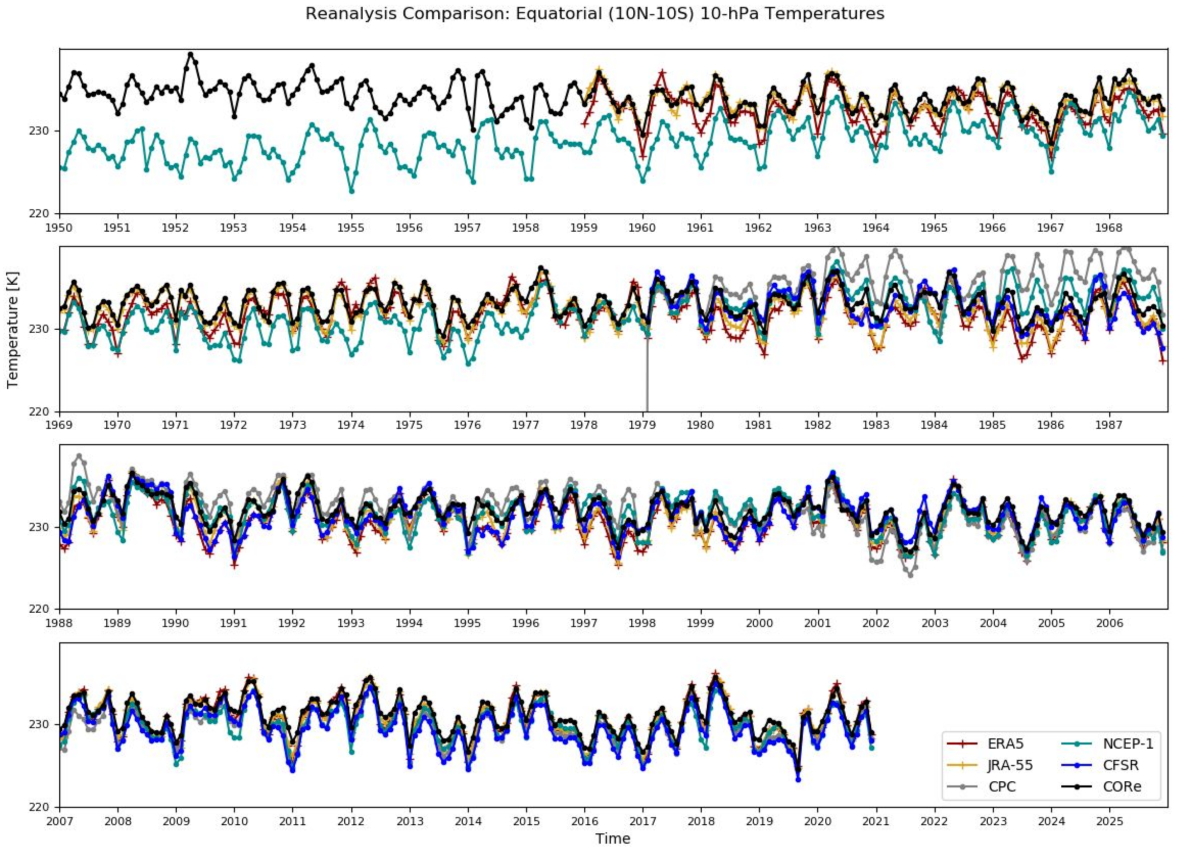
- Purpose: Examine whether differences evident in the seasonal cycle are confined to specific time period or are consistent across 1979-2020

- CORe typically falls within in the range of other reanalysis temperature values
  - ERA tends to be warmer at different periods
  - JRA tends to be colder across the period



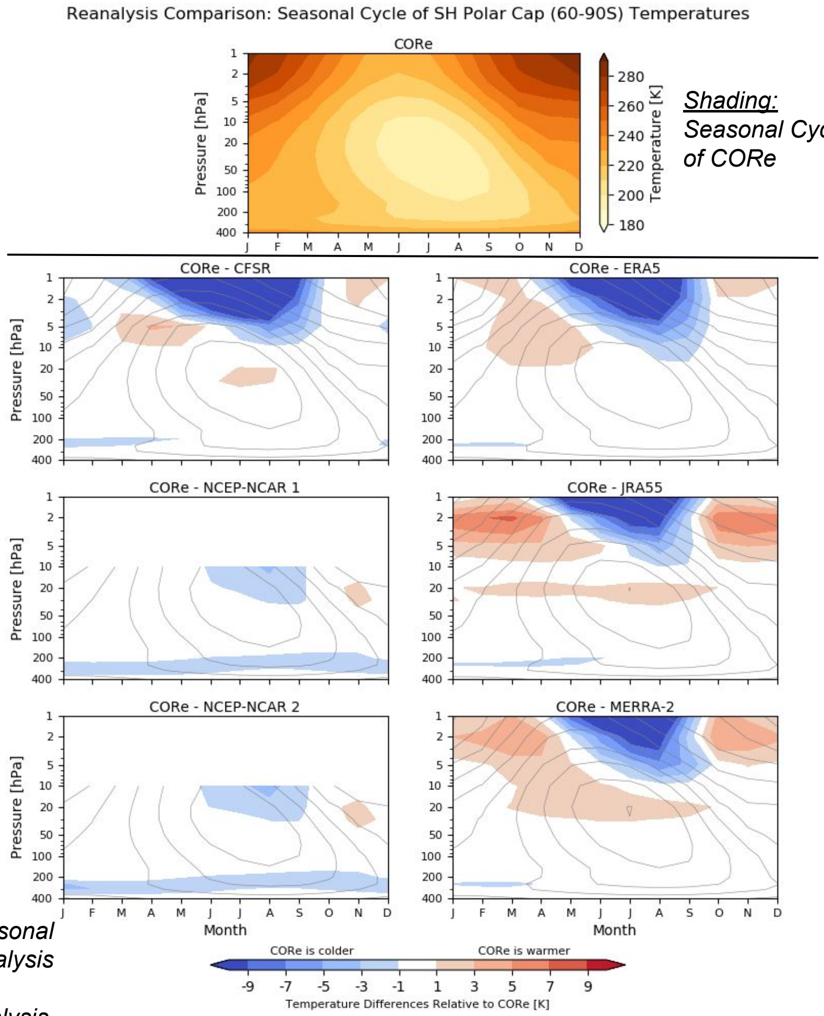
Time Series of 10-hPa Equatorial Temperatures

- By 10-hPa, the differences between the re-analyses are considerably smaller
- Less “cold-bias” in JRA-55
  - CORe, ERA5 and JRA-55 are generally consistent
- Differences between CORe and NCEP-1 are quite large 1950-1977
- NCEP-1 is colder than other reanalyses through 1977



Seasonal Cycle of <u>SH</u> Polar Cap Temperatures (1979-2020)

- Period: 1979-2020 → so that CFSR, MERRA-2 and NCEP-2 could be included
- Note pressure level extends down to 400-hPa
- Strong differences occur in upper stratosphere (<10-hPa)
- Relative to other reanalyses, CORe exhibits a cold bias during the austral winter
  - Boreal winter cold bias is strongest relative to CFSR but noticeable in other reanalyses
- Warm summer biases are strongest relative to JRA55 (and MERRA2 to a lesser extent)



<u>Shading:</u> Seasonal Cycle of CORe

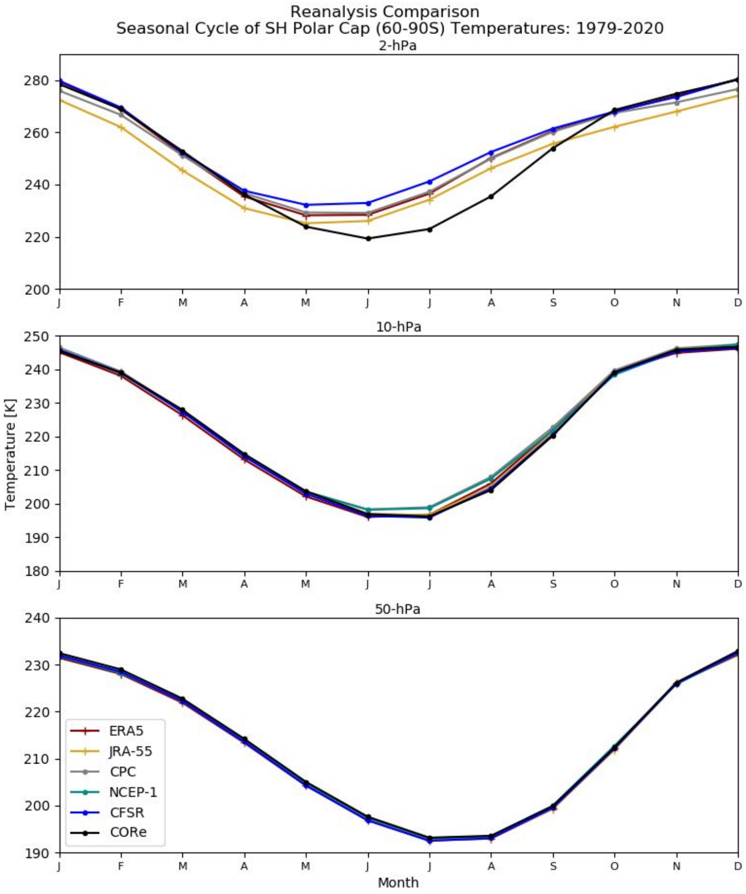
<u>Contours:</u> Seasonal Cycle of Reanalysis
<u>Shading:</u>
CORe - Reanalysis

Seasonal Cycle at SH Stratospheric Polar Cap (1979-2020)

- Note MERRA-2 and NCEP-2 are not analyzed
  - Too many lines→ cluttered figure; MERRA-2 results similar to JRA/ERA; NCEP-2 similar to NCEP-1
  - Added CPC/AMSU stratospheric temperature analysis

- 2-hPa: differences are strongest
  - CORe colder in austral winter months (particular June-September)
  - JRA-55 is consistently colder throughout all months

- 10/50-hPa: Agreement increases with with pressure



Comparison of SH Stratospheric Polar Cap Seasonal Cycle Periods

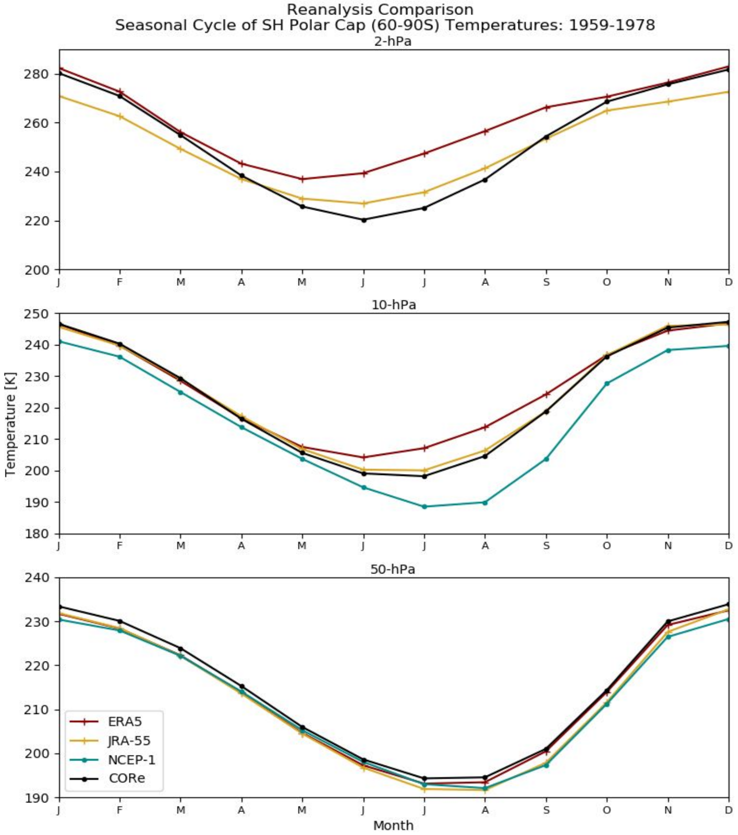
Purpose: Examine if seasonal cycles exhibit noticeable differences prior to 1979-2020 period.

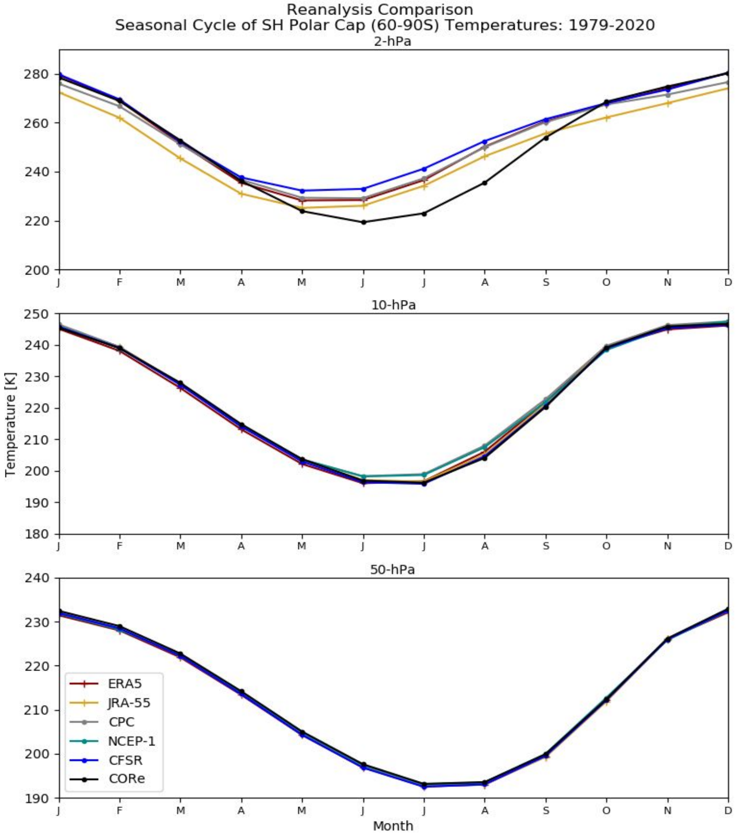
Comparison period: 1959-1978 → 4 re-analyses overlapped during this period

1959-1978: ERA noticeably warmer during early period at 2-hPa

1959-1978: NCEP-1 colder than others at 10-hPa

Agreement at 10/50-hPa not as good as in NH



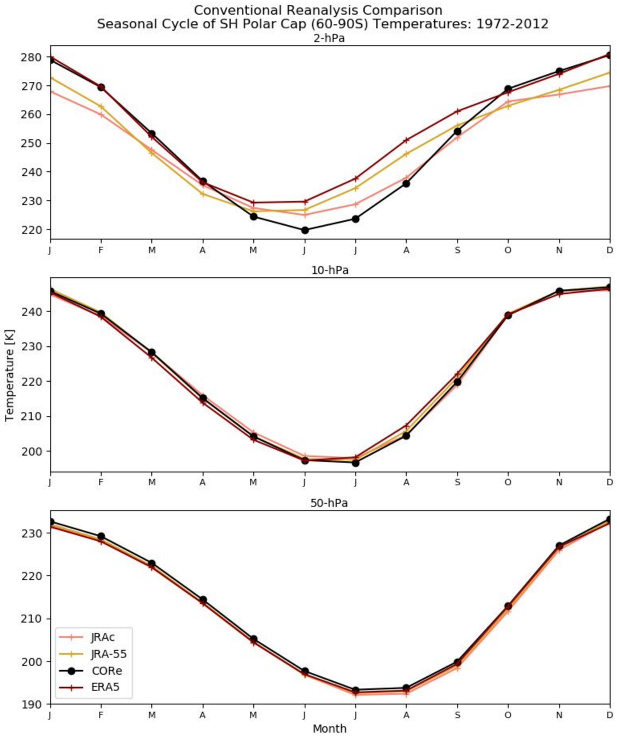


Comparison of SH Stratospheric Polar Cap Seasonal Cycle with JRAc

Add in JRA conventional only

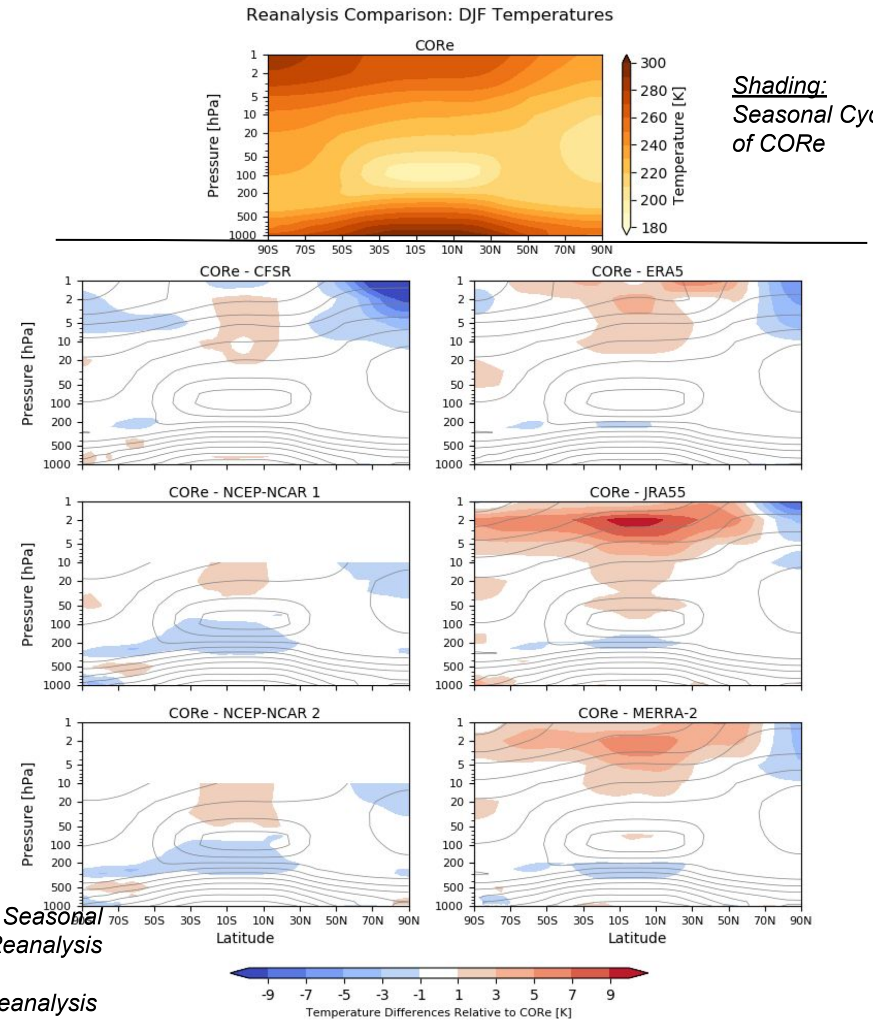
Only runs 1979-2012

JRAc also has a cold bias compared to ERA/JRA but it's not as strong as CORe



Boreal Winter (DJF) Zonal Mean Temps (1979-2020)

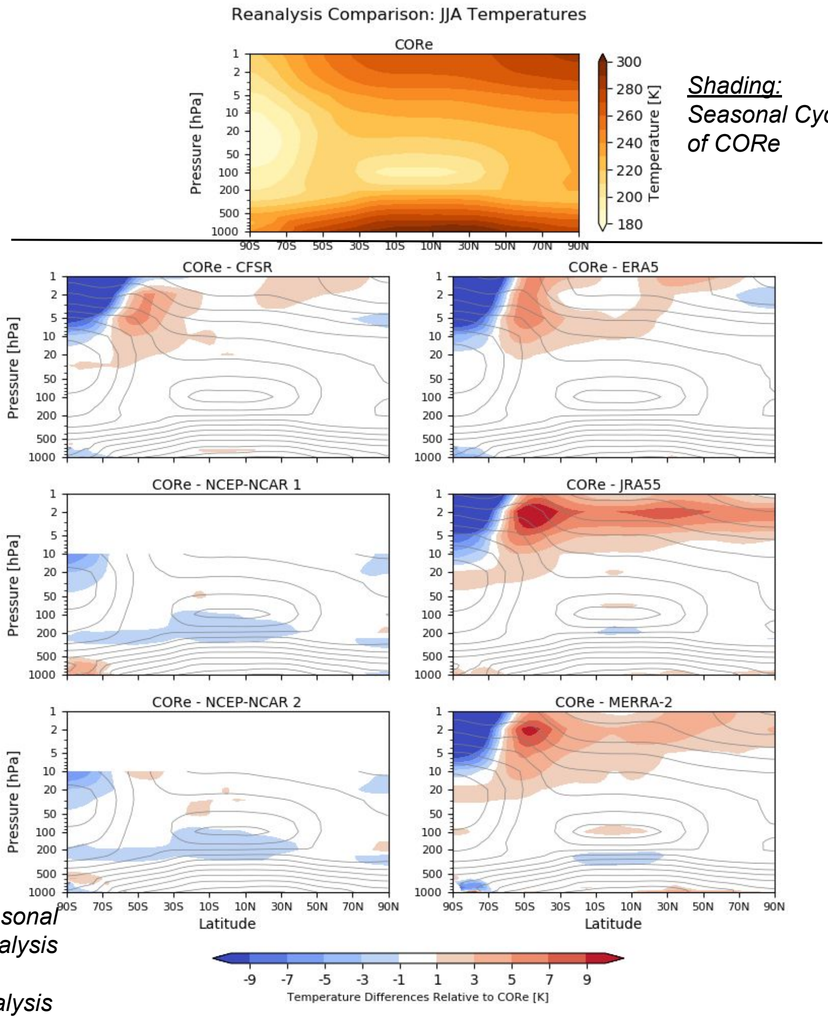
Latitude-pressure differences



Shading: Seasonal Cycle of CORe

Contours: Seasonal Cycle of Reanalysis
Shading: CORe - Reanalysis

Austral Winter (JJA) Zonal Mean Temps (1979-2020)



__Shading:__ Seasonal Cycle of CORe

__Contours:__ Seasonal Cycle of Reanalysis
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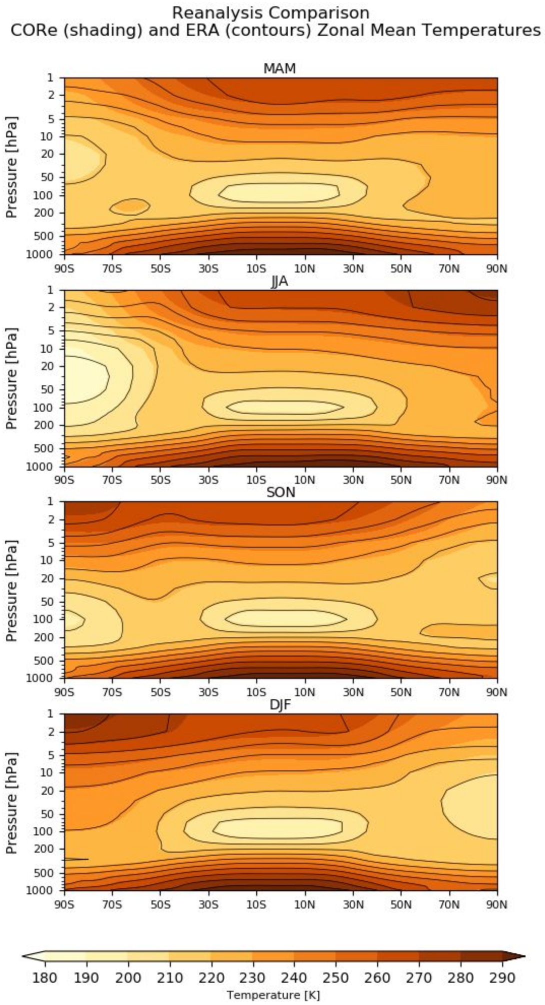
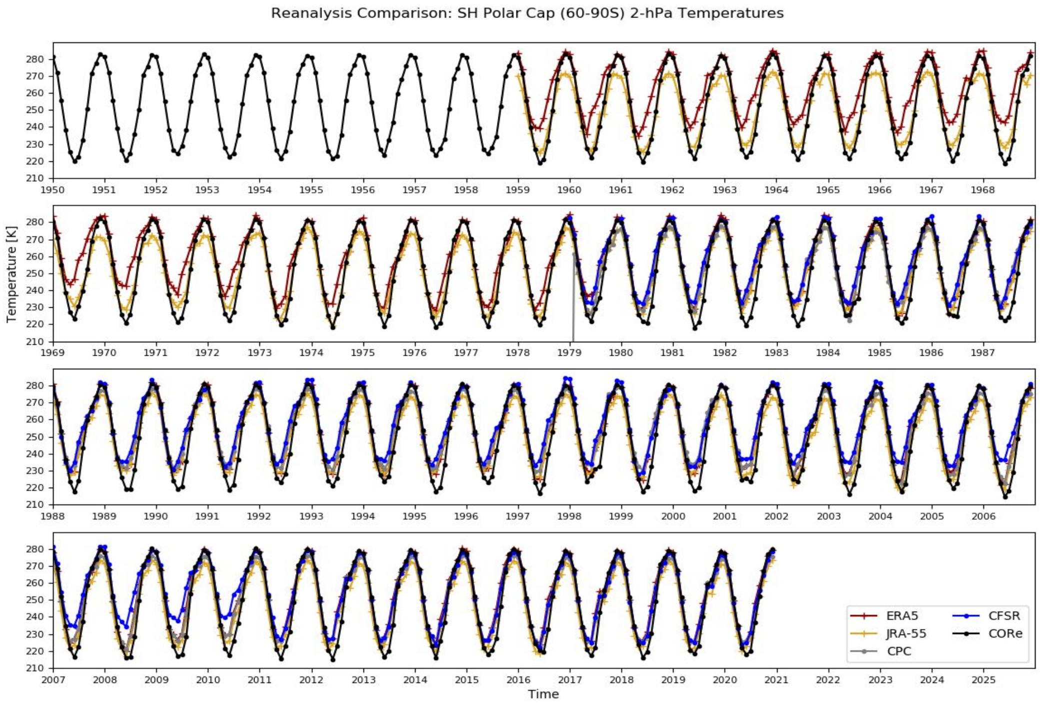
CORe - Reanalysis

CORe/ERA comparison of Zonal Mean Temperatures (1979-2020)



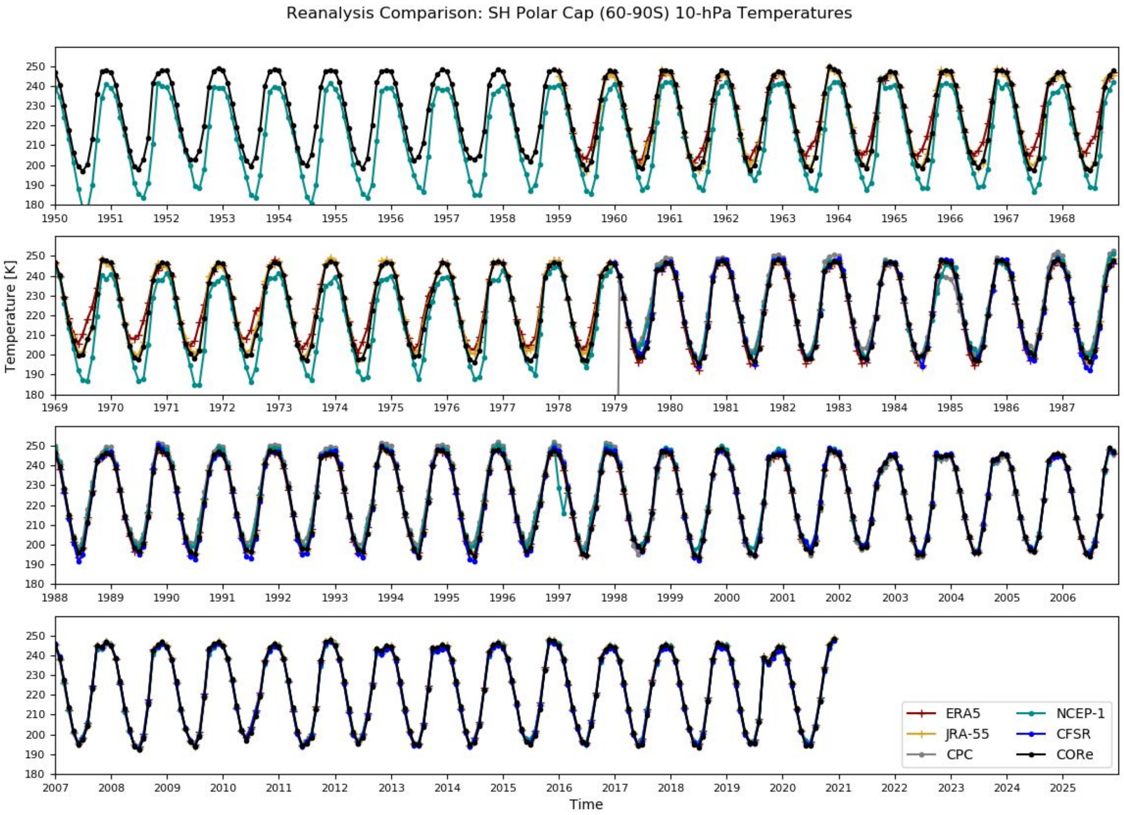
Time Series of 2-hPa SH Polar Cap Temperatures

- Purpose: Examine whether differences evident in the seasonal cycle are confined to specific time period or are consistent across 1979-2020
- CORe typically is consistently colder than other re-analyses throughout the period
- CFSR is consistently warmer than other re-analyses throughout the period
- ERA-5 winter temperatures are considerably warmer than JRA-55/CORe prior to 1979.
  - The seasonal cycle of ERA-5 seems like it changes prior to 1979 while CORe looks more stable throughout the period. This is consistent with results on previous slide



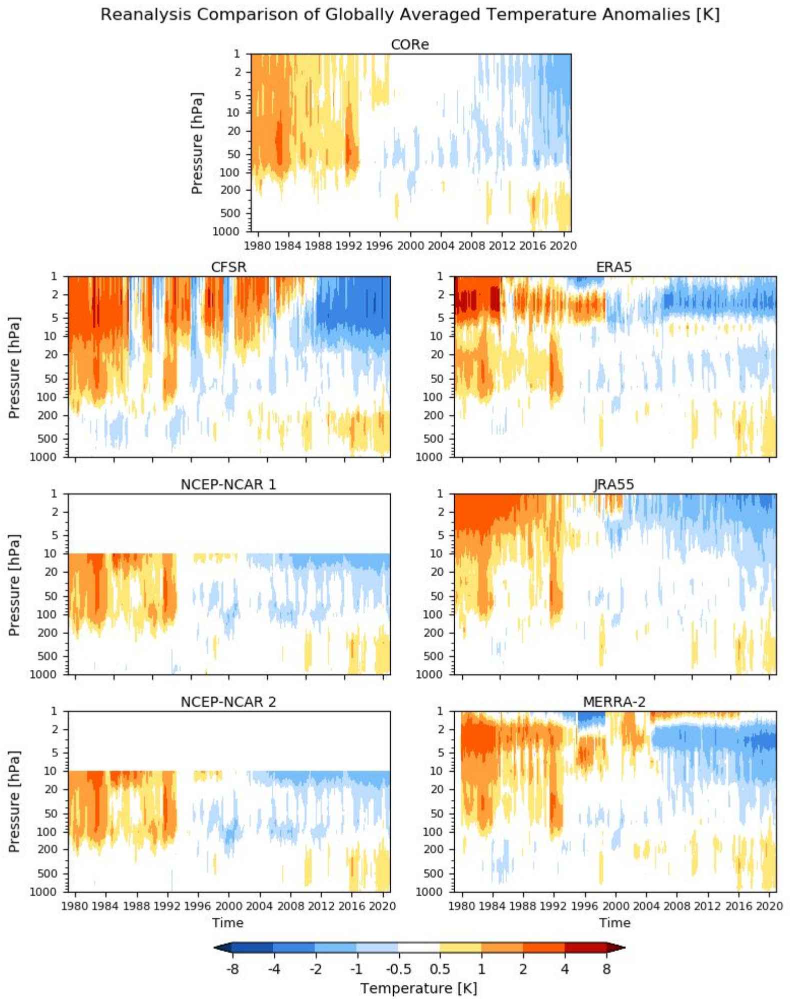
Time Series of 10-hPa SH Polar Cap Temperatures

- By 10-hPa, the differences between the re-analyses are considerably smaller
- Largest differences occur prior to 1979
  - Particularly NCEP-1, which is much colder than other reanalyses since 1950s



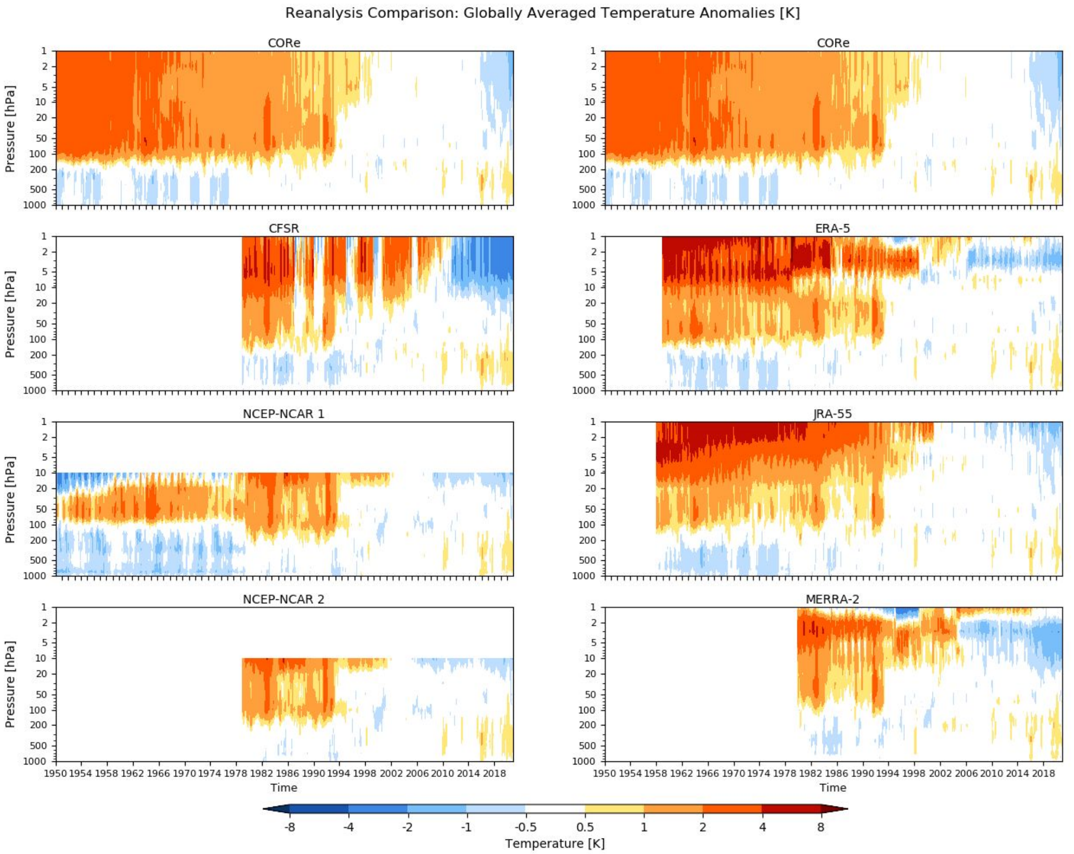
Globally Averaged Temperature Anomalies (1979-2020)

- Analysis: globally averaged (cos-weighted) temperature anomalies (1979-2020 clim mean)
- Note: analysis extends down to 1000-hPa
- Considerable improvement over CFSR in the stratosphere
- Similar structure between CORe and other reanalyses
    - anomalously warm during the first 15 years of the record and then transitioning to anomalously cool
- Amplitudes of the anomalies in the middle/upper stratosphere are generally weaker in CORe
- Strongest differences in the sign of the anomalies occurs ~1-hPa (ERA/MERRA)

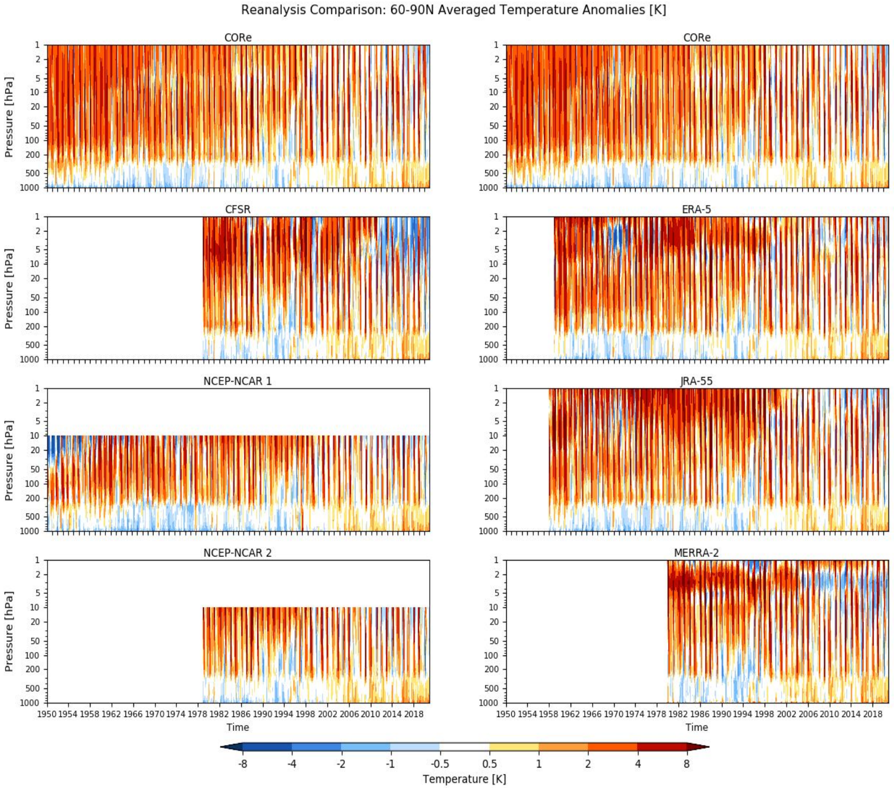


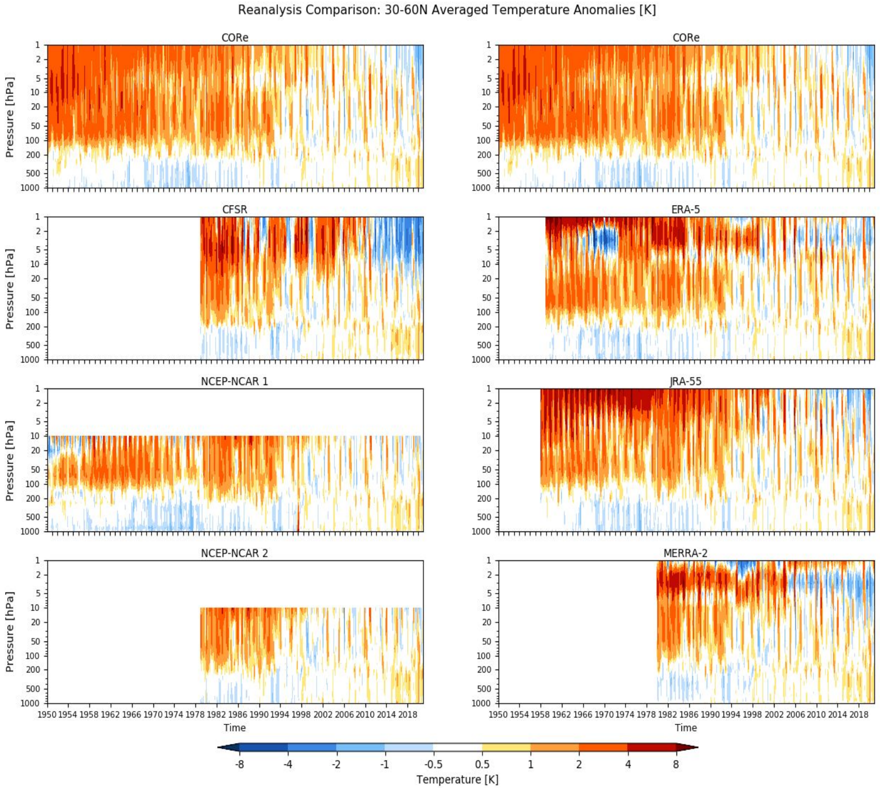
Globally Averaged Temperature Anomalies (All Available Years)

- Based on 1991-2020 climatological means
- Same as previous but extends back as far as each reanalysis goes
- Prior to 1979, only other available reanalyses ar NCEP-1, ERA-5, and JRA-55
- NCEP-1 exhibits cold anomalies 10-20hPa that are out of phase with other reanalyses
- ERA5/JRA-55 are same sign as CORe but amplitudes are stronger

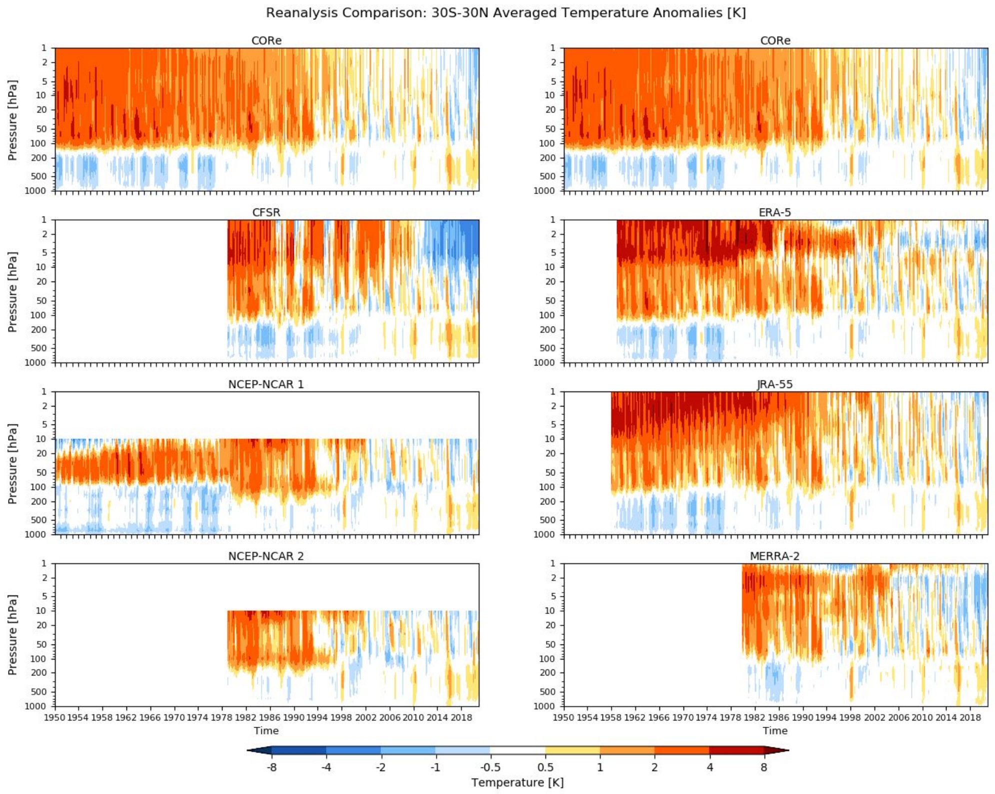


NH Zonal Bands of Averaged Temperature Anomalies (All Available Years)

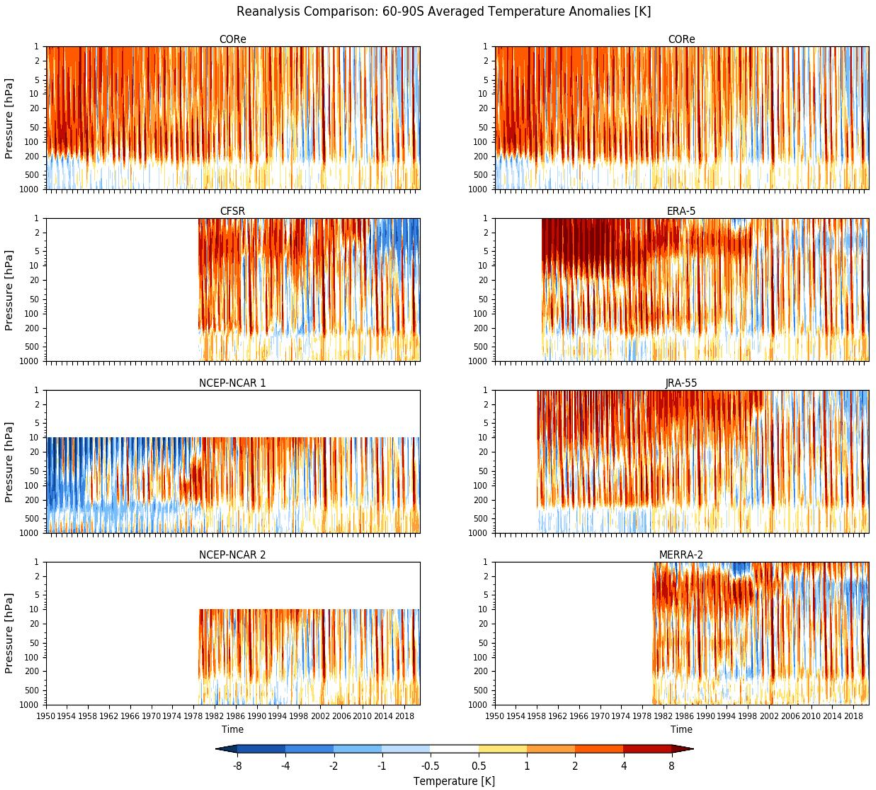


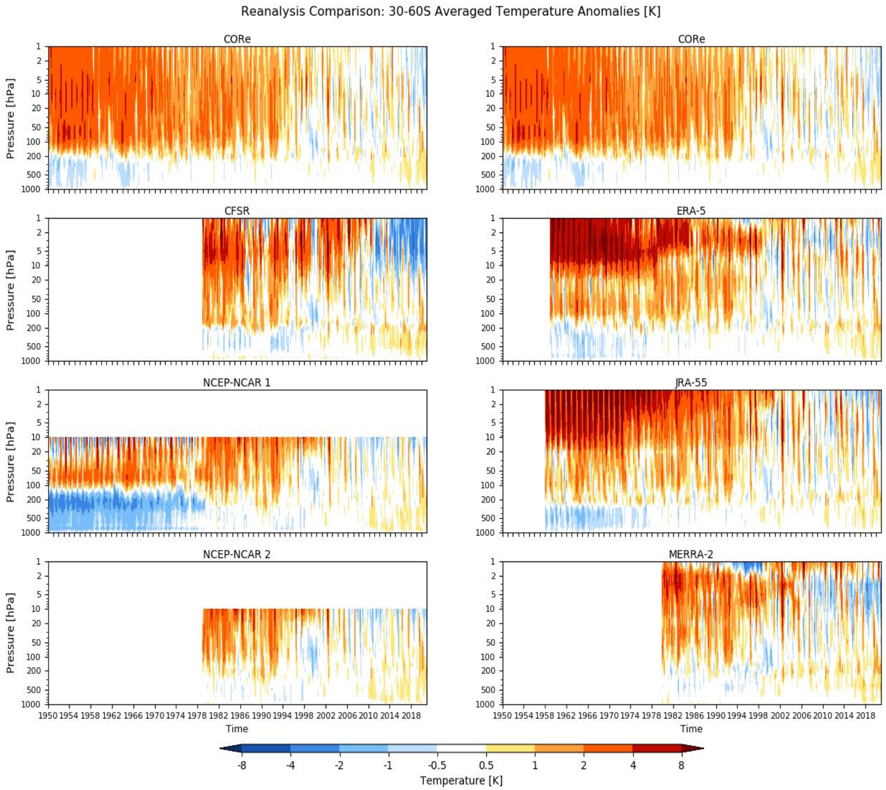


Equatorial Bands of Averaged Temperature Anomalies (All Available Years)



SH Zonal Bands of Averaged Temperature Anomalies (All Available Years)





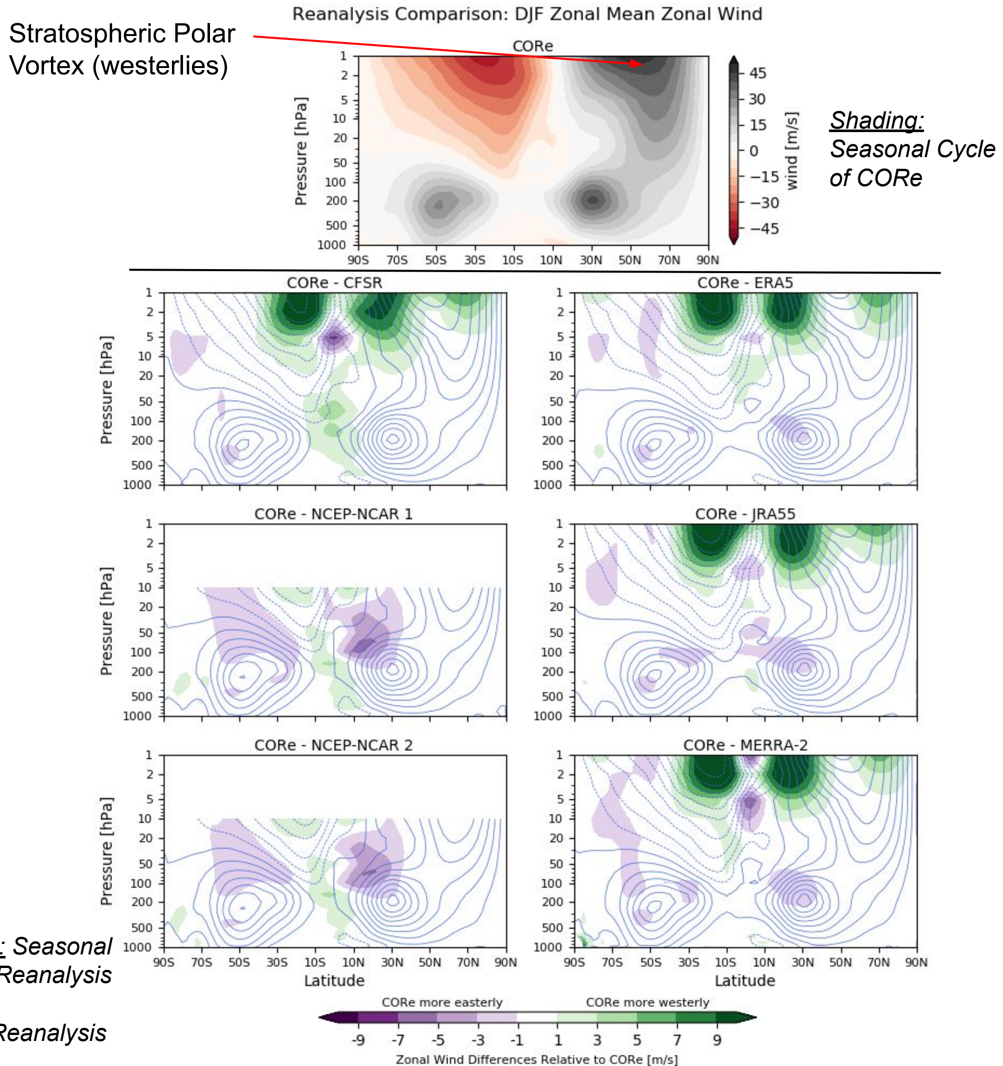
Summary of Monthly Mean Temperatures

- Largest between CORe and other reanalyses are evident above 10-hPa (particularly above 5-hPa)
    - Overall largest discrepancies exist in SH → not unsurprising given the lack of SH conventional observations
    - SH winter → CORe is colder than other reanalyses
    - CORe has warm bias relative to JRA-55 and MERRA-2. But in reality JRA-55 seems to have a cold bias relative to most reanalyses.
- Below 10-hPa: agreement is strong between CORe and other reanalyses
    - Prior to 1979 - CORe more consistent with ERA/JRA than NCEP-1 which has a stronger colder bias relative to others
- Noticeable improvement in CORe relative to CFSR - particularly with regard to global temperature anomalies
- Still to do:
    - Look at other conventional reanalyses → Have JRAc, but are there others?

Zonal Mean Zonal Winds

Boreal Winter (DJF) Zonal Mean Zonal Winds (1979-2020)

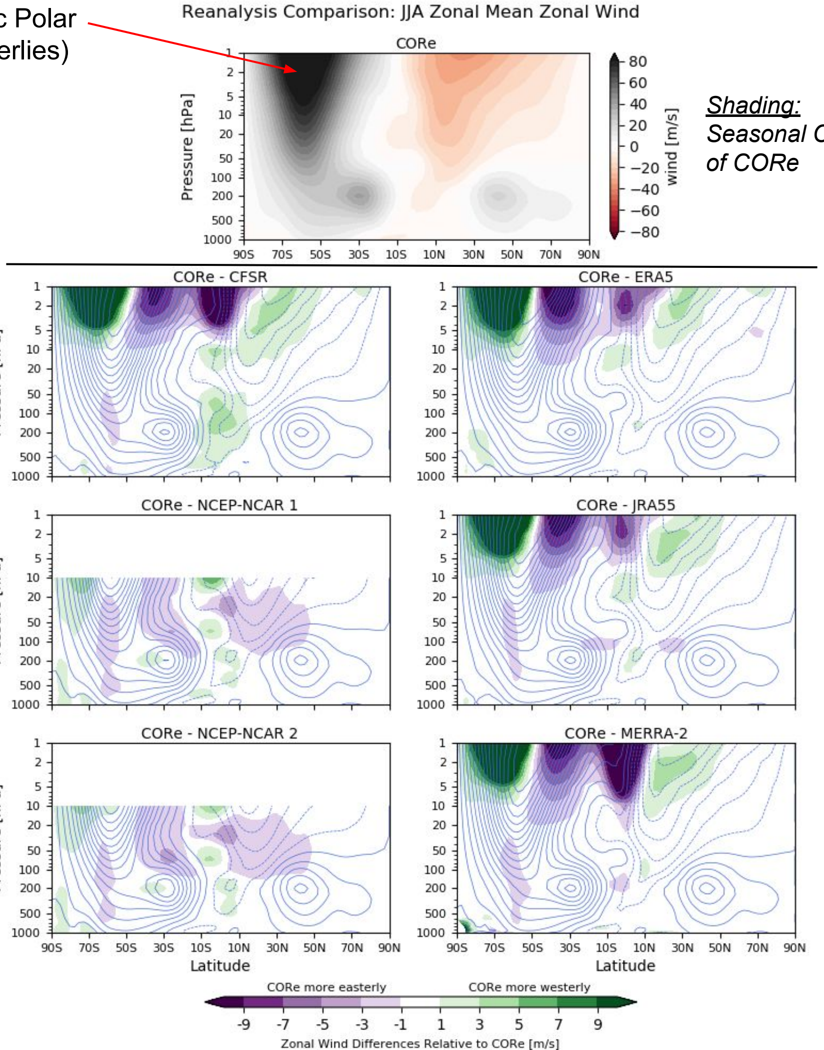
- Analysis: latitude-height plots of zonal mean zonal winds (U) averaged over DJF
- Note: x-axis is different from Temperature plots
- Boreal winter: NH stratospheric polar vortex at 60N
- Strong westerly bias in upper stratosphere (above 5-hPa)
    - Upper component of NH polar vortex broader in CORe than in other reanalyses
    - Climatological easterlies in SH are weaker in CORe than in other reanalyses
    - See the slide after next for direct comparison



Austral Winter (JJA) Zonal Mean Zonal Winds (1979-2020)

- Analysis: latitude-height plots of zonal mean zonal winds (U) averaged over JJA
- Austral winter: SH stratospheric polar vortex at ~60S
- Strong biases in CORe in upper stratosphere tropics/SH (above 10-hPa)
  - Poleward shift and relative broadening of upper portion of CORe's polar vortex?
  - Other reanalyses a slight equatorward tilt of the westerlies above 5-hPa that is less evident in CORe
- Biases are smaller at ~10-hPa
- Climatological NH upper stratospheric easterlies are slightly weaker in CORe (or maybe just shifted slightly equatorward)

Stratospheric Polar Vortex (westerlies)



Shading: Seasonal Cycle of CORe

Contours: Seasonal Cycle of Reanalysis
Shading: CORe - Reanalysis

CORe/ERA comparison of Zonal Mean Zonal Winds (1979-2020)

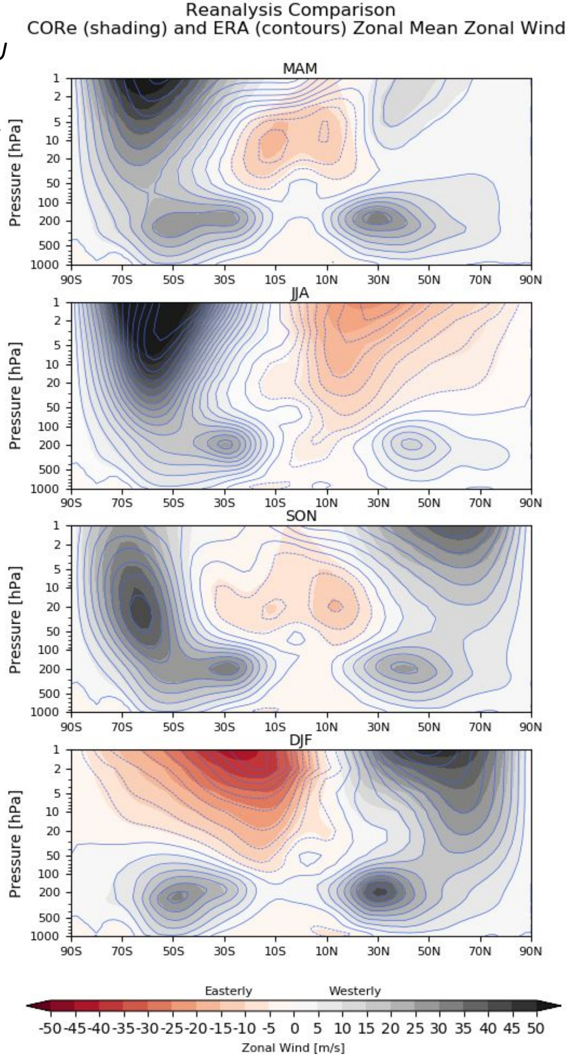
- Easier to see the differences between CORe and other re-analyses just by overlaying them
  - Only showing comparison with ERA-5 which seems representative across other reanalyses

- JJA (Austral winter)
  - SH: CORe westerlies above 5-hPa:
    - Don't tilt equatorward so weaker than reanalyses (easterly bias on equatorward side);
    - Stronger and extend deeper/further south (westerly bias on poleward side)
  - 0N-30N: Strongest CORe easterlies extend further equatorward (easterly bias)

- DJF (Boreal winter)
  - NH: strongest CORe westerlies are broader and extend deeper (westerly bias)
  - SH: CORe easterlies are weaker and are not as shifted/extended equatorward (westerly bias)

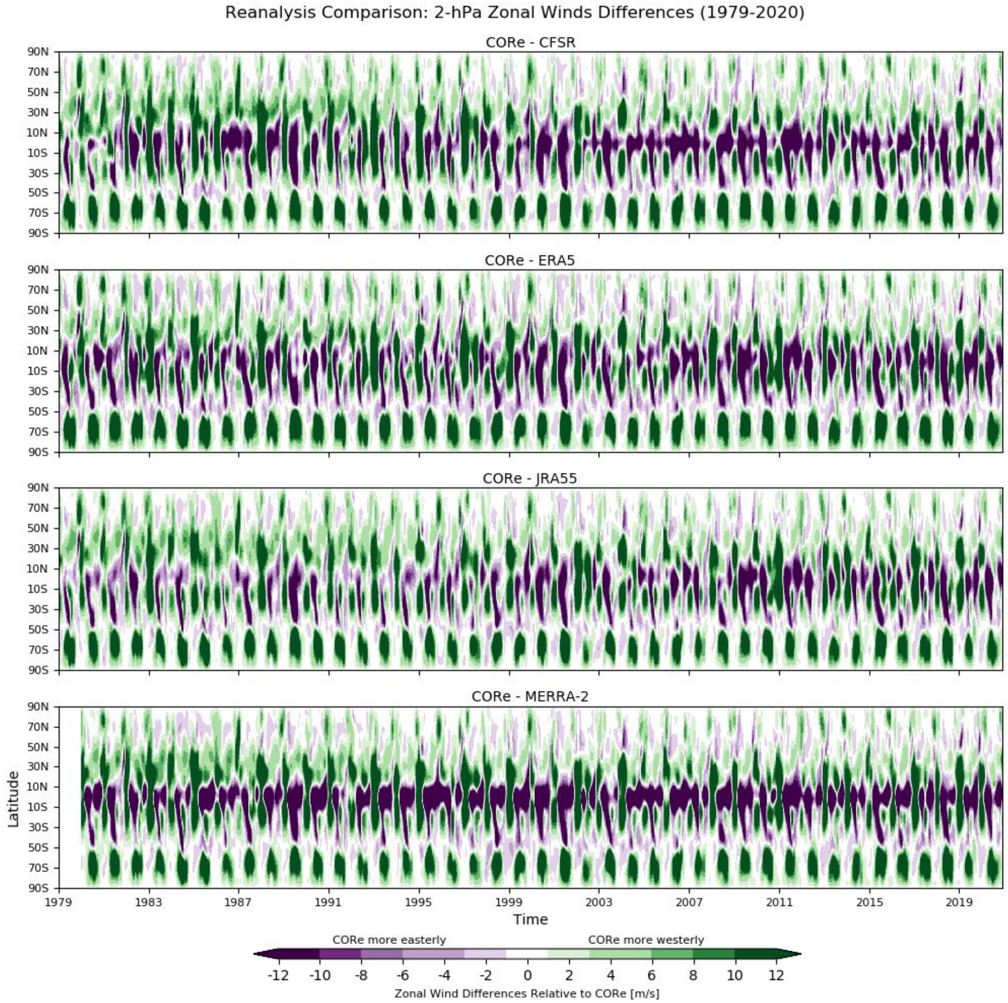
- MAM and SON (Shoulder seasons)
  - ERA westerlies tend to extend to equator ~2hPa while CORe has weak easterlies (easterly bias)

<u>*Shading:*</u>
CORe climatological U
<u>*Contours:*</u>
Reanalysis climatological mean U



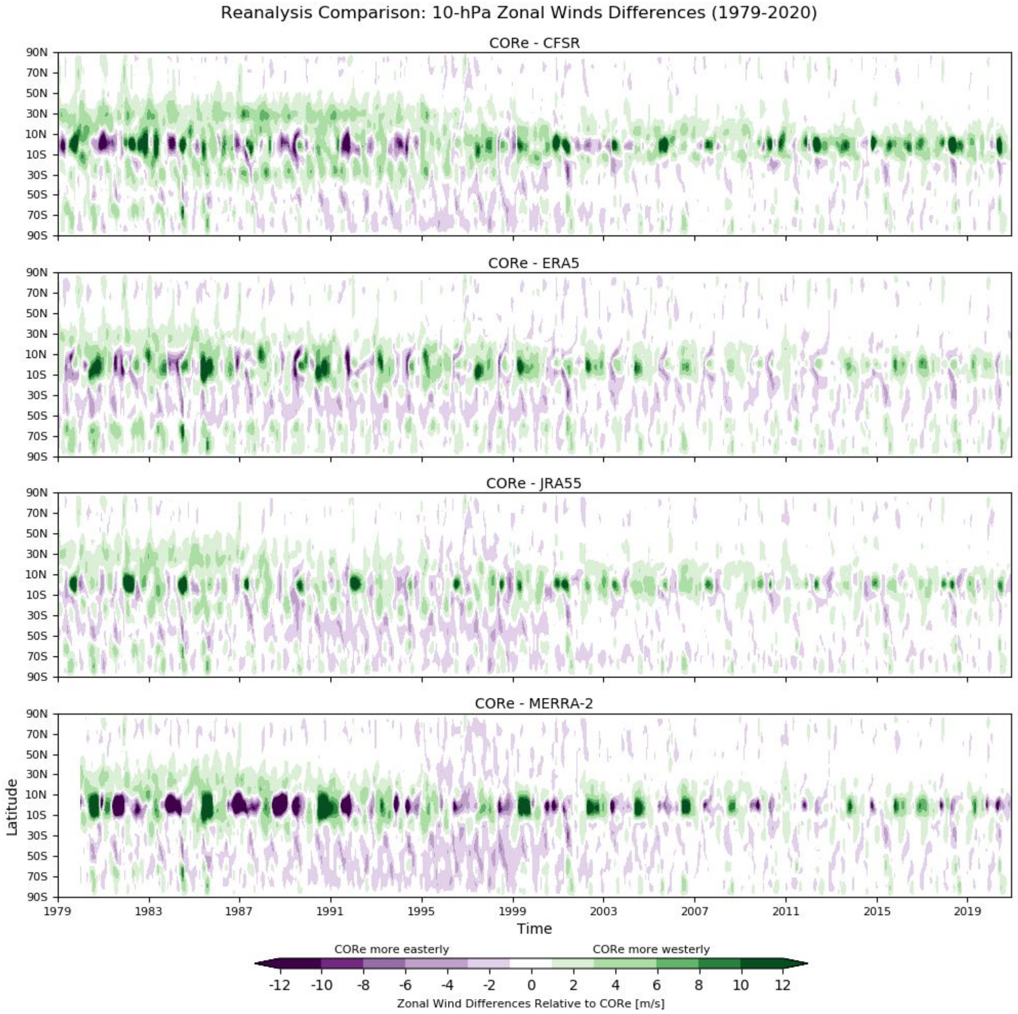
Time Series of 2-hPa Zonal Mean Wind Differences (1979-2020)

- Analysis: Latitude-Time plots - Examine whether differences evident in the seasonal cycle are confined to specific time period or are consistent across 1979-2020
- Shading: Differences are relative to CORe
- NCEP re-analyses not included because they don't extend to 2-hPa
- Strongest differences between CORe and reanalyses 10N-30S and 50-70S are consistent with previous slides
- Differences occur across 1979-2020 period



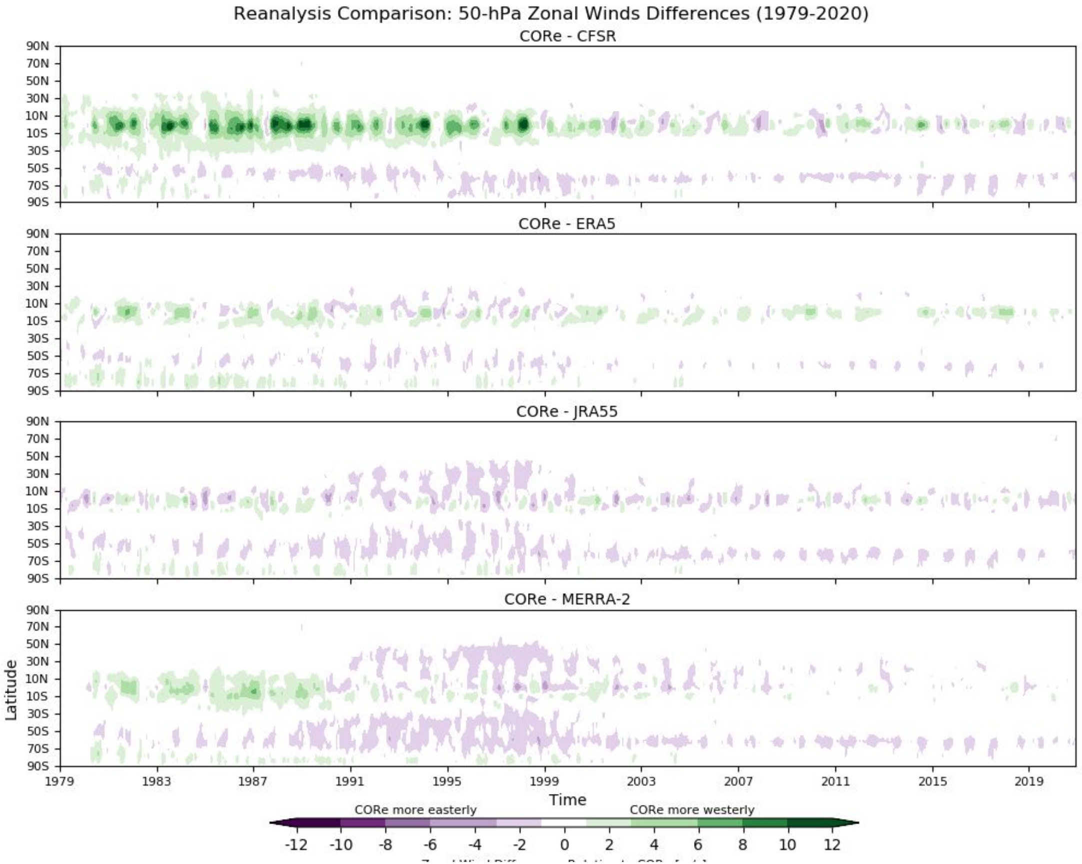
Time Series of 10-hPa Zonal Mean Wind Differences (1979-2020)

- Differences are relative to CORe
- Differences are generally smaller than at 2-hPa
- Largest differences are across the equatorial region
- Differences decrease with time, particularly for ERA5 and JRA-55
- It's promising that differences are smaller at 10-hPa 60N and 60S because this is where the stratospheric polar vortex is typically defined



Time Series of 50-hPa Zonal Mean Wind Differences (1979-2020)

- Differences are relative to CORe
- Differences are noticeably smaller than at 2-hPa
- Largest differences are with respect to the CFSR but differences decrease with time
- CORe is largely consistent ERA5 and JRA-55
- It’s promising that differences are smaller at 50-hPa across the equator because this region is important for the QBO
-



Summary of Zonal Mean Zonal Winds

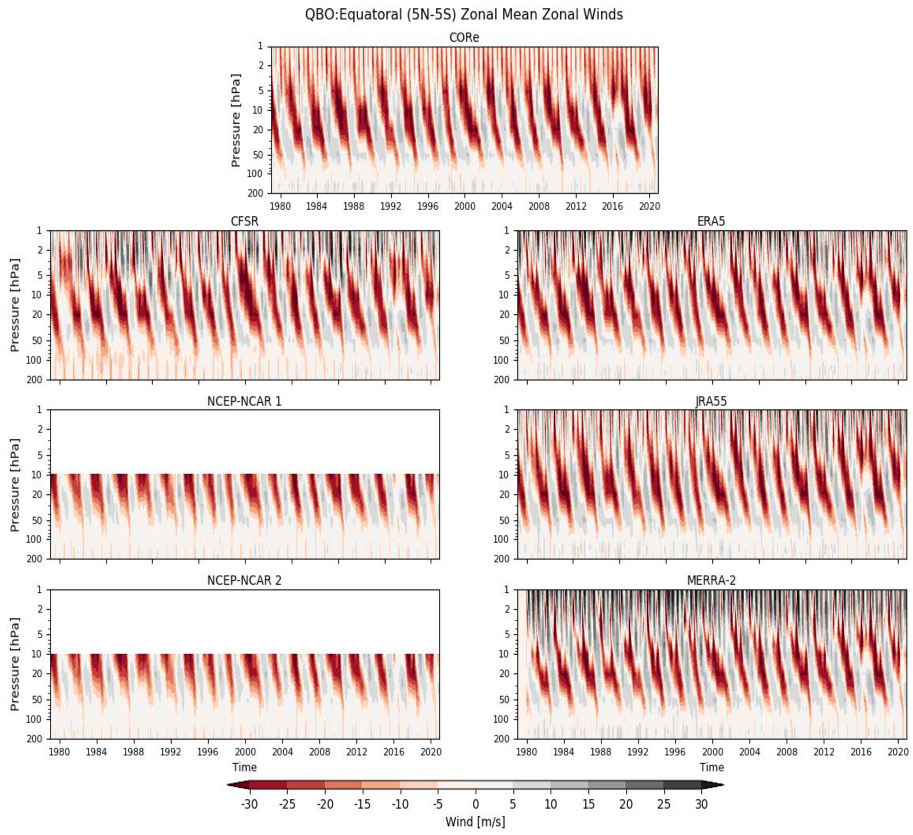
- Similar to temperatures, largest differences between CORe and other reanalyses occur in upper stratosphere SH winter
    - CORe westerlies tend to be stronger and extend further poleward (band of strongest westerlies is broader)
- Also noticeable differences between CORe and other reanalyses in equatorial region across the seasons
    - Winter hemispheres (JJA/DJF) : CORe winter hemisphere easterlies tend to extend further in to equatorial region
    - Shoulder seasons (MAM/SON): weak equatorial easterlies extend through stratosphere in CORe, but are westerly in other reanalyses
- Differences weaken by 10-hPa
- Differences are smaller at ~10-hPa 60N/60S where polar vortex (and SSWs) are defined
- Differences are smaller at 50-hPa in the equatorial region where QBO indices are defined

Analysis of QBO

Analyses on next slides are typically of zonal mean zonal wind over 5N-5S
Note: I know there were issues with producing QBO in CFSR and ERA-40 winds were used; I wasn't sure if similar issues existed with CORe so I analyzed it anyway assuming there were not

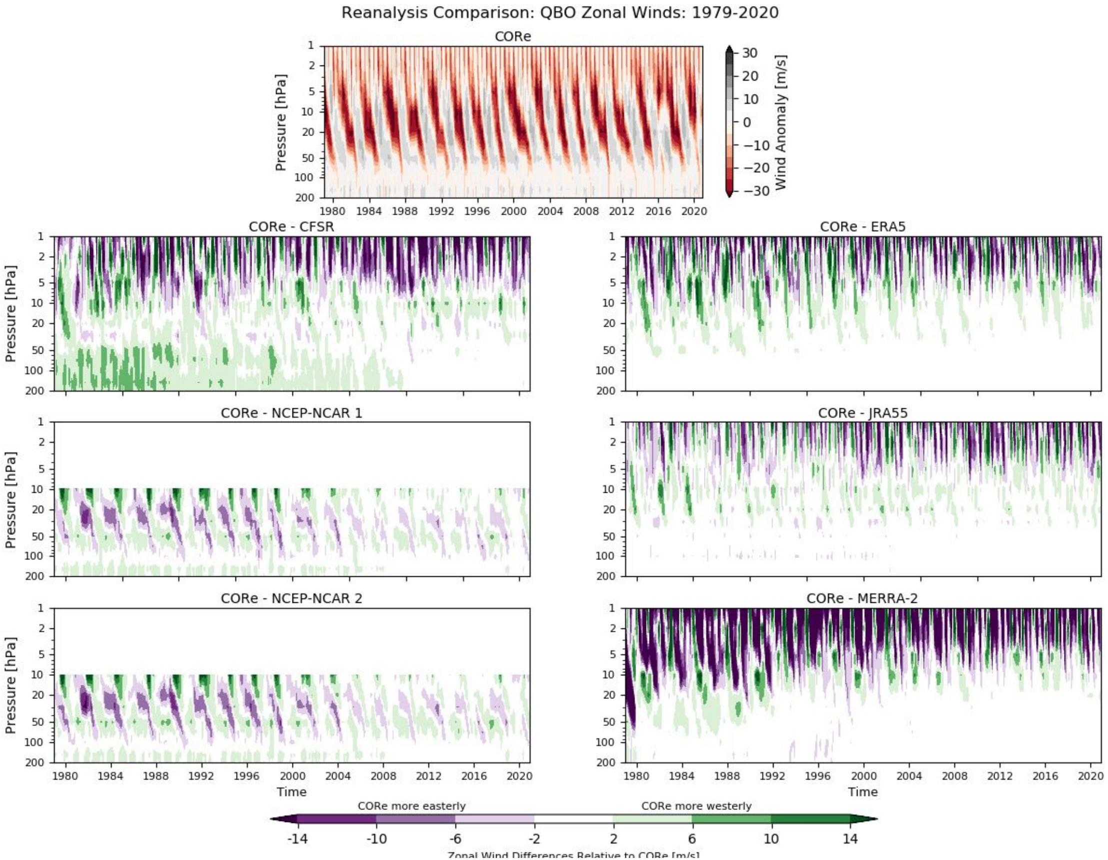
Comparison of QBO Time Series (1979-2020)

- Analysis: Pressure - Time plots of QBO Winds
- Note pressure extends to 200-hPa
- It’s not easy to make a comparison using these figures other than to say CORe has a reasonable looking QBO
- CORe seems to have a stronger/more frequent easterlies above 2-hPa



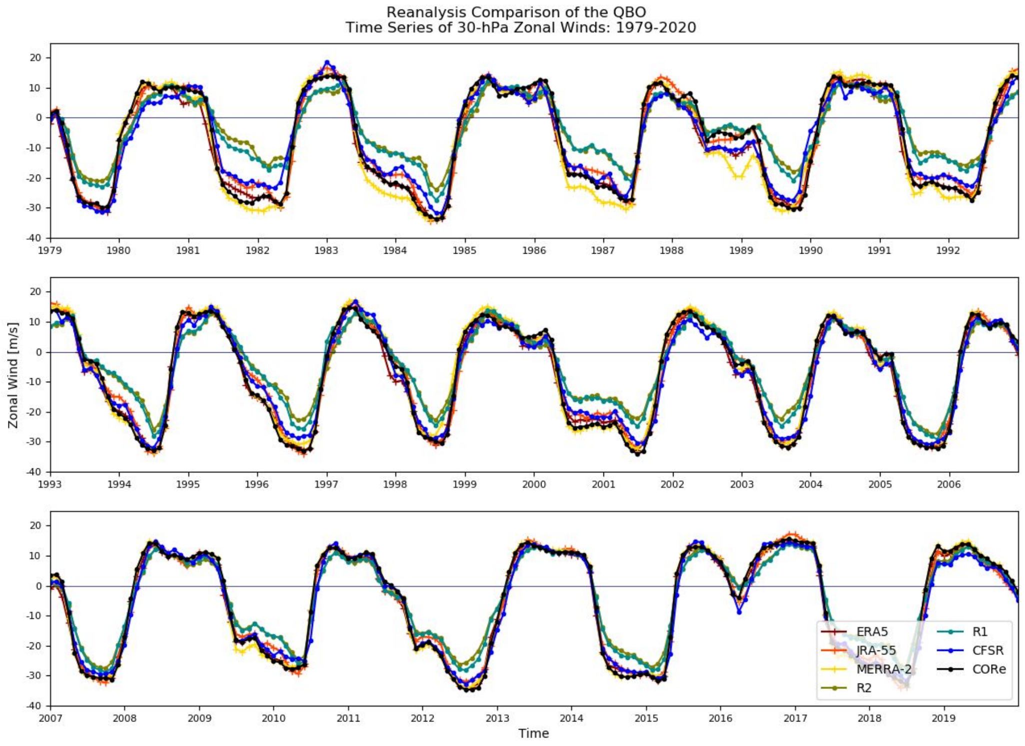
Comparison of QBO Time Series Differences (1979-2020)

- Analysis: Pressure - Time plots of QBO Winds Differences (CORe - Reanalysis)
- Note pressure levels extends to 200-hPa
- Differences in the zonal winds weaken considerably below 10-hPa for ERA5 and JRA-55
- Below 10-hPa CORe differences with ERA/JRA are smaller than differences with NCEP/CFSR reanalyses
- Stronger differences wrt CFSR and MERRA-2
- Differences below 10-hPa decrease with time in all reanalyses



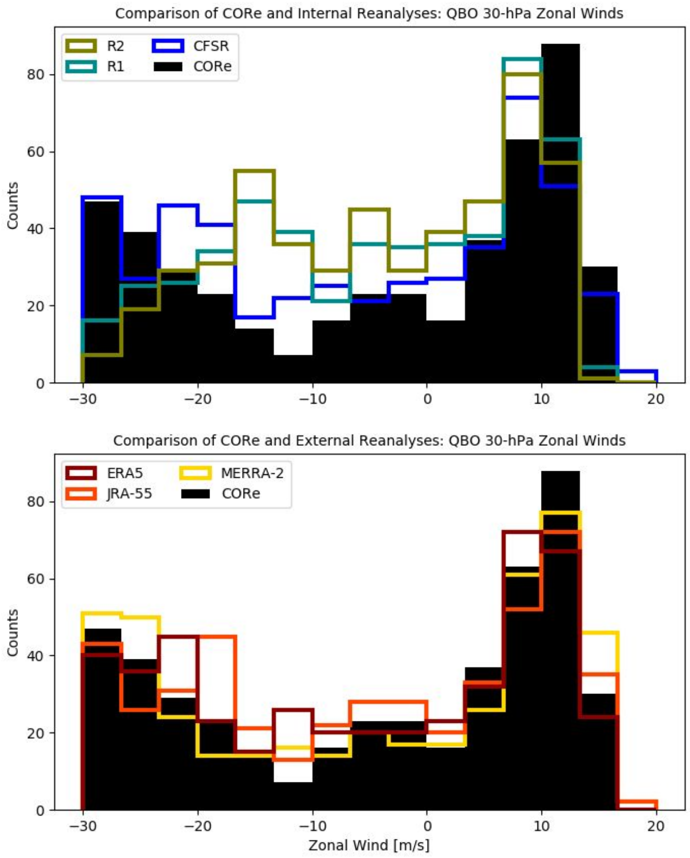
Time Series of QBO Winds at 30-hPa (1979-2020)

- CORe typically falls within the range of winds from each reanalysis
- NCEP-reanalyses tend to underestimate the easterlies



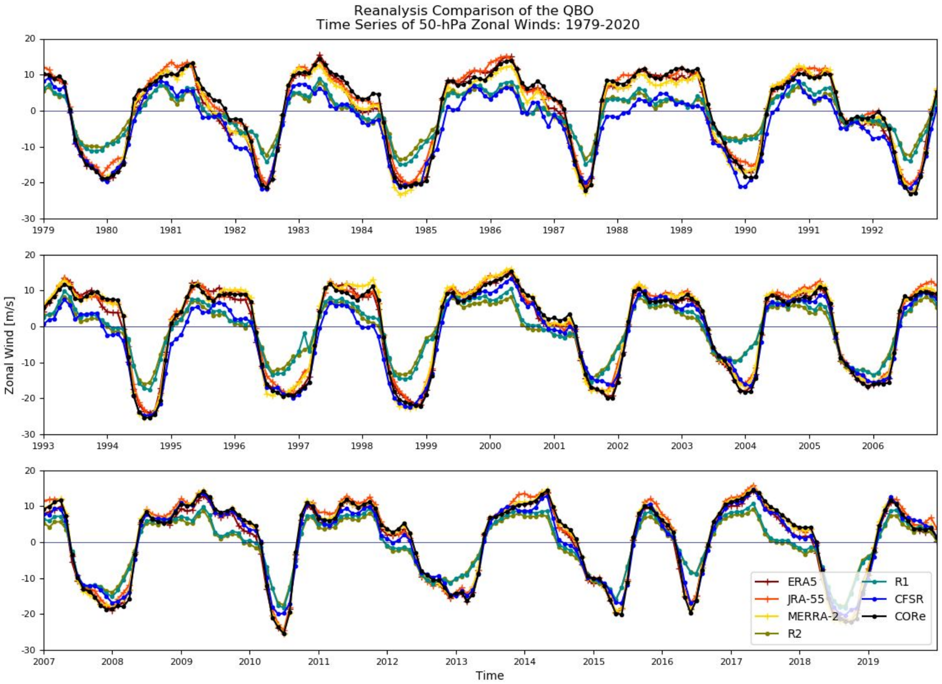
Histogram of Equatorial Zonal Winds at 30-hPa

- Analysis: histogram of zonal mean zonal U values
  - Top panel: Comparison between CORe and internal reanalyses
  - Bottom panel: COmparison between CORe and external reanalyses
- Figure is admittedly messy and hard to read
  - But if you stare hard enough, it confirms that NCEP-reanalyses underestimate the easterlies (and also the westerlies to some extent)
  - More agreement with with external reanalyses at least in terms of getting the correct range of amplitudes



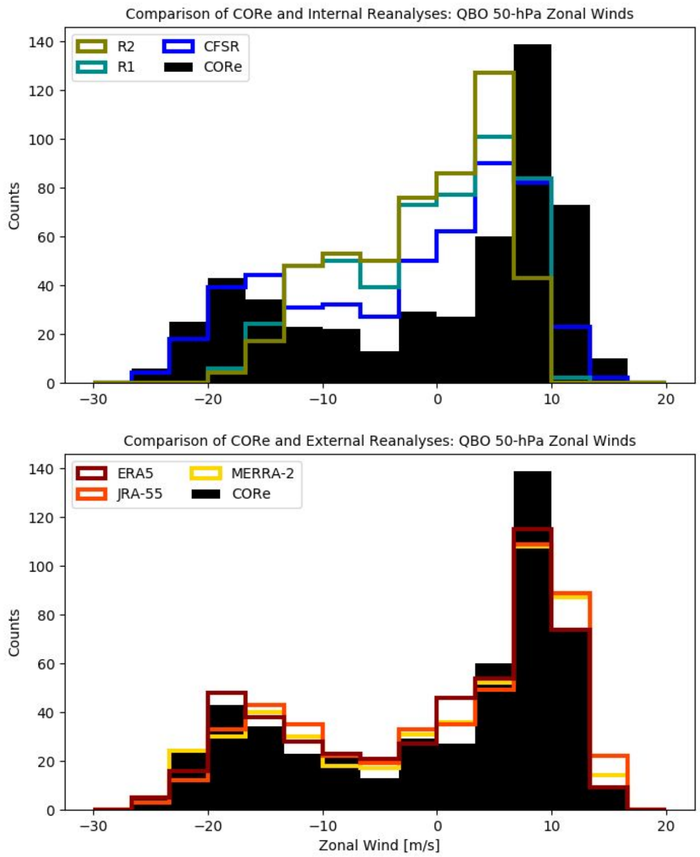
Time Series of QBO Winds at 50-hPa (1979-2020)

- CORe typically falls within the range of winds from the external reanalyses
- NCEP -reanalyses tend to underestimate both easterlies and westerlies → more muted QBO
    - More noticeable in the first part of the record



Histogram of Equatorial Zonal Winds at 50-hPa

- Analysis: histogram of zonal mean zonal U values
  - Top panel: Comparison between CORe and internal reanalyses
  - Bottom panel: COmparison between CORe and external reanalyses
- Figure is easier to read than at 30-hPa
  - NCEP-reanalyses underestimate the easterlies and westerlies
  - CFSR also mutes the QBO but not as much as NCEP-1/2
  - CORe agrees well with external reanalyses



Summary of QBO comparisons

- CORe is more consistent with external reanalyses
- CORe QBO is less “muted” than in CFSR or NCEP Reanalyses-1/2

Analysis of Extratropical Stratospheric Variability

Coming Soon