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Using the Stratosphere for Extended Range Prediction

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CLIVAR
Panel Report

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Some questions……

- What is the impact of stratospheric circulations on climate/weather prediction?
  - Stratospheric circulations are predictable, are an importance source of variability on seasonal and interannual time scales.
  - Definite impact of improved stratosphere on NWP skill.
  - Teleconnections identified involving wave-mean flow interactions primarily in NH, seasonally dependent

- How good are climate models in predicting stratospheric circulations?
  - Coupled chemistry climate models (CCM's) simulate climatology reasonably well;
  - NWP systems extending to high altitudes have some skill on seasonal time scales
  - Predicting events (e.g., stratospheric sudden warmings, recent QBO disruption) still problematic.

- Is there enough data to evaluate the stratospheric circulations in the models?
  - Currently, probably yes. In the near future, maybe not….

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Some questions……

- What is the impact of stratospheric circulations on climate/weather prediction?

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Improved stratosphere can increase short-range forecast skill

Extension of Navy's earlier NWP system from 30 km to 70 km with new physics and new satellite radiance assimilation together produced significant increases in tropospheric forecast skill
[Gerber et al., BAMS, 2012]

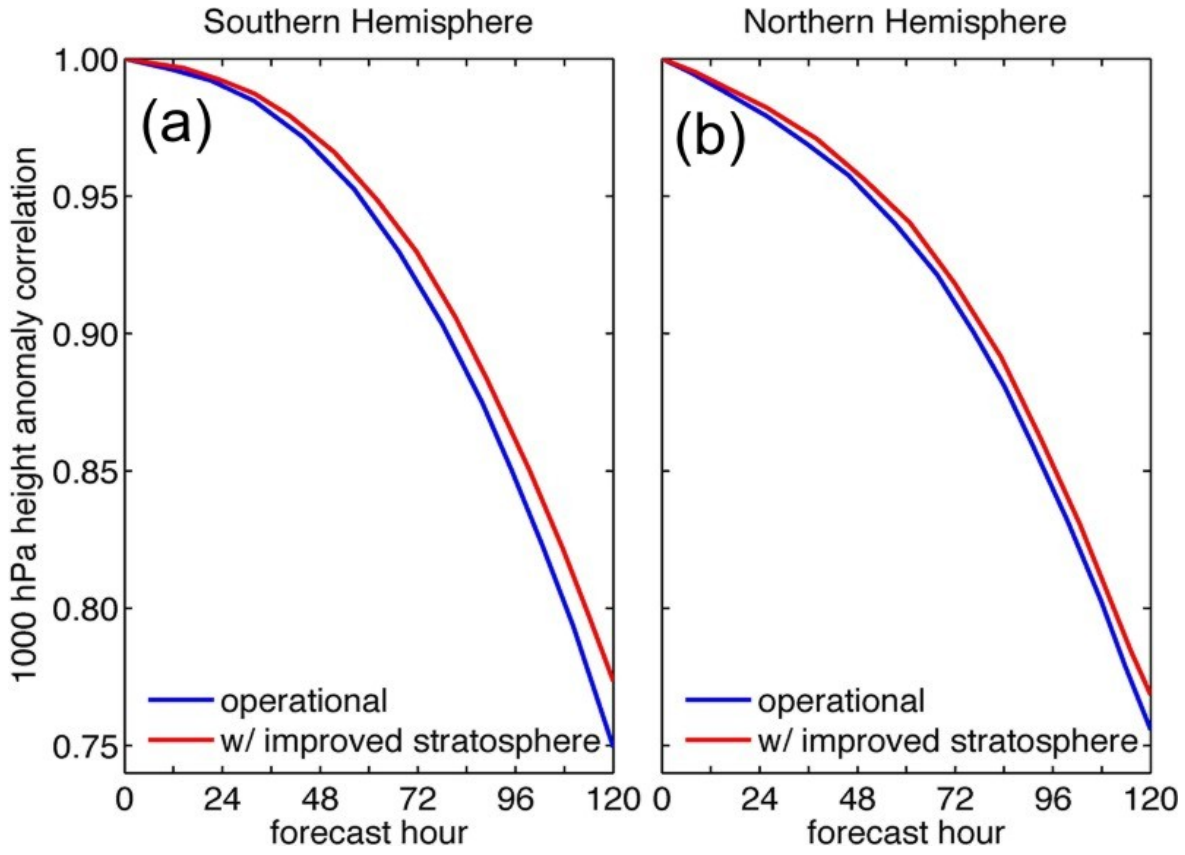


Figure courtesy B. Ruston NRL-MRY

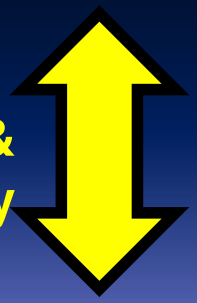
The Stratosphere is Important for Extended Range Prediction

Stratosphere & Mesosphere
10-85 km

Large Angular Momentum Reservoir
Long Radiative/Dynamical Time Scales
Long Memory *(weeks to months)*

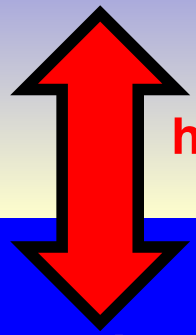
> ***"the stratosphere's potential to improve seasonal forecasts is largely untapped"*** **(NAS 2010)**

wave momentum & energy



Troposphere
0-10 km

Short Radiative/Dynamical Time Scales
Short Memory *(hours to days)*

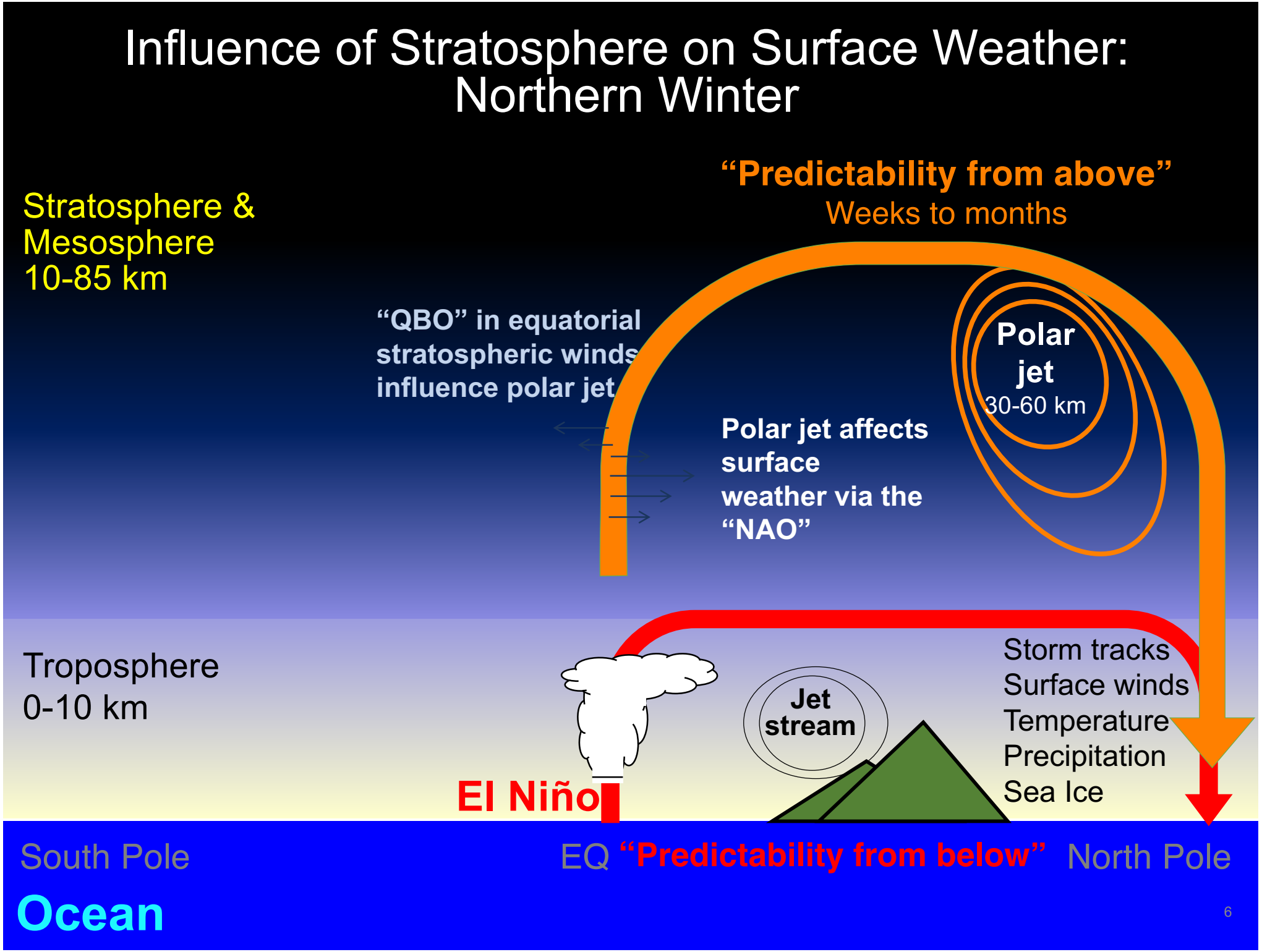


heat

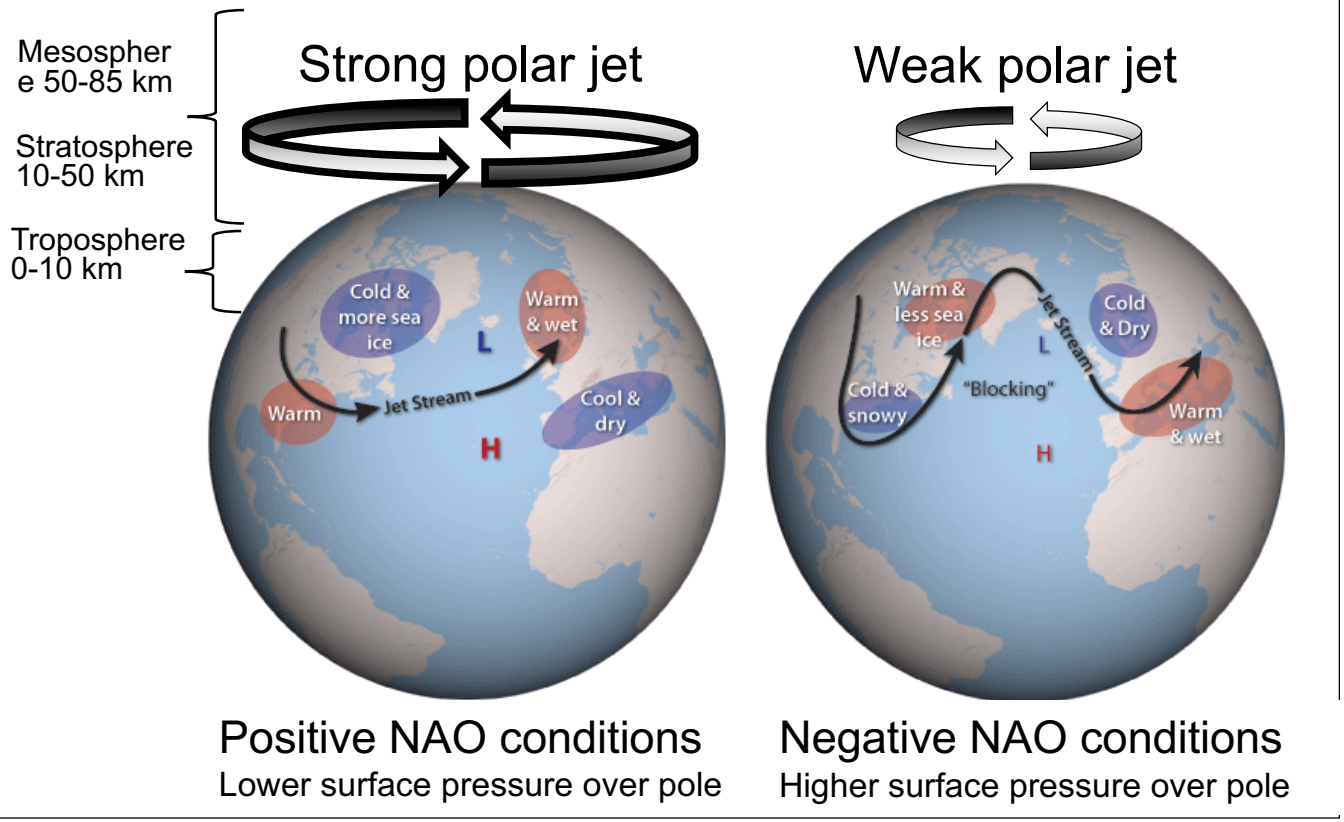
Ocean

Large Heat Reservoir
Long Time Scales, *Long Memory* ***(months to years)***

Influence of Stratosphere on Surface Weather: Northern Winter



Dynamic Coupling: Northern Winter



Positive NAO conditions
Lower surface pressure over pole

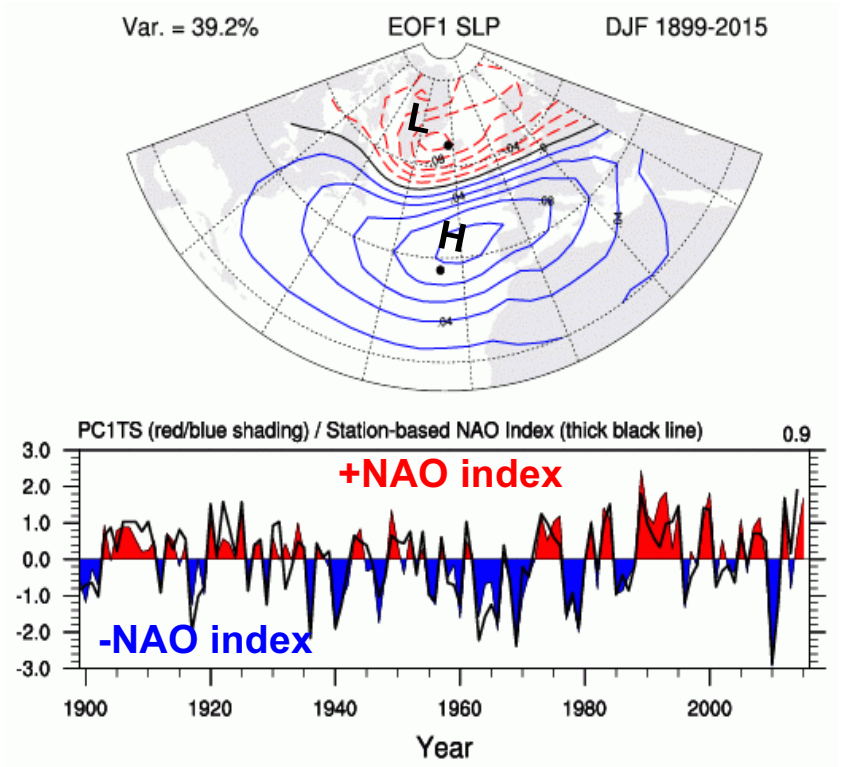
Negative NAO conditions
Higher surface pressure over pole

Similar patterns are also observed in the Southern Hemisphere
→ Antarctic Oscillation (AAO)

Vertically deep circulation pattern known as the North Atlantic Oscillation (**NAO**) links strength of polar jet to jet stream & surface pressure patterns.

Sudden weakening/reversal of polar jet can impact seasonal weather patterns over entire hemisphere [Kidston et al., *Nature Geosci.*, 2015].

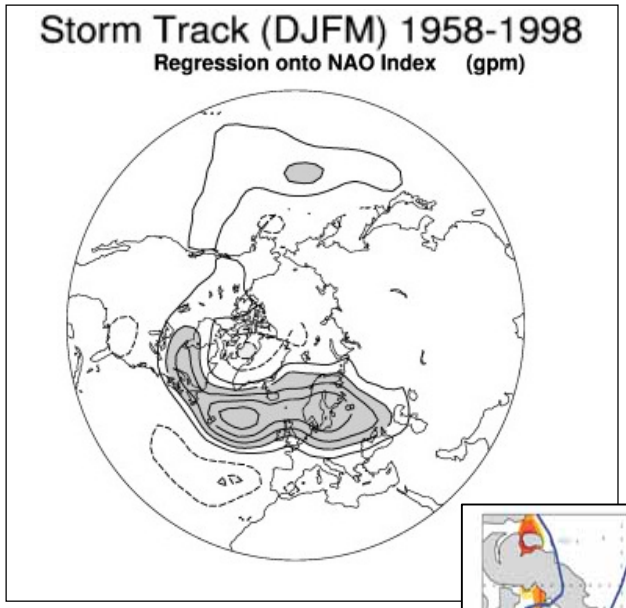
Seasonal prediction systems must include the stratosphere and mesosphere to capture this coupling and exploit "**predictability from above**".



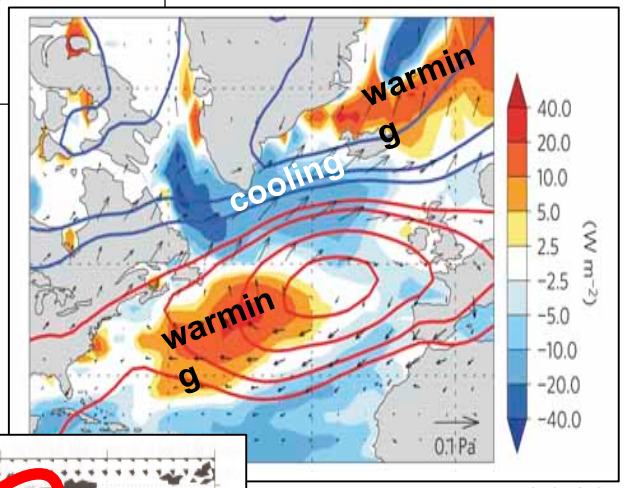
NAO index derived from statistical analysis of sea level pressures (SLP) describes leading mode of variability.

When NAO index is positive:

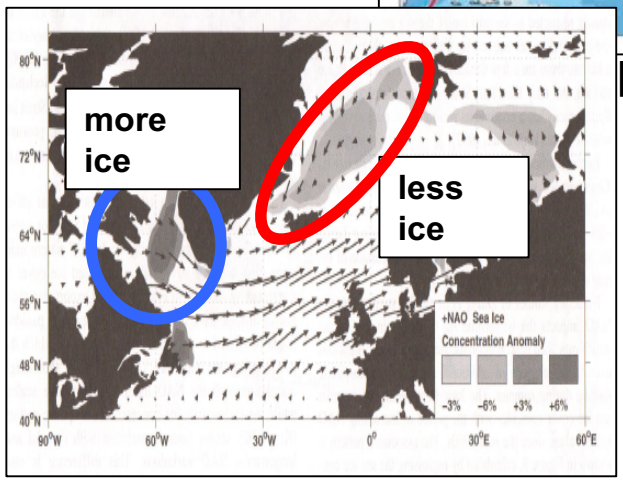
- Lower polar surface pressures
- Storm track location shifts northward
- Surface heating & cooling impacts Arctic sea ice



[Hurrell and Deser, 2010]

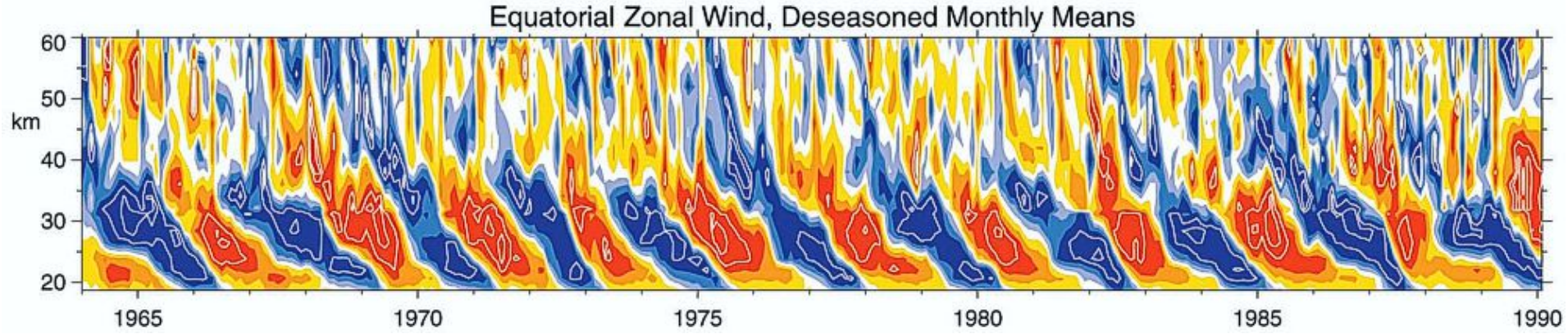


[Reichler at al., 2012]



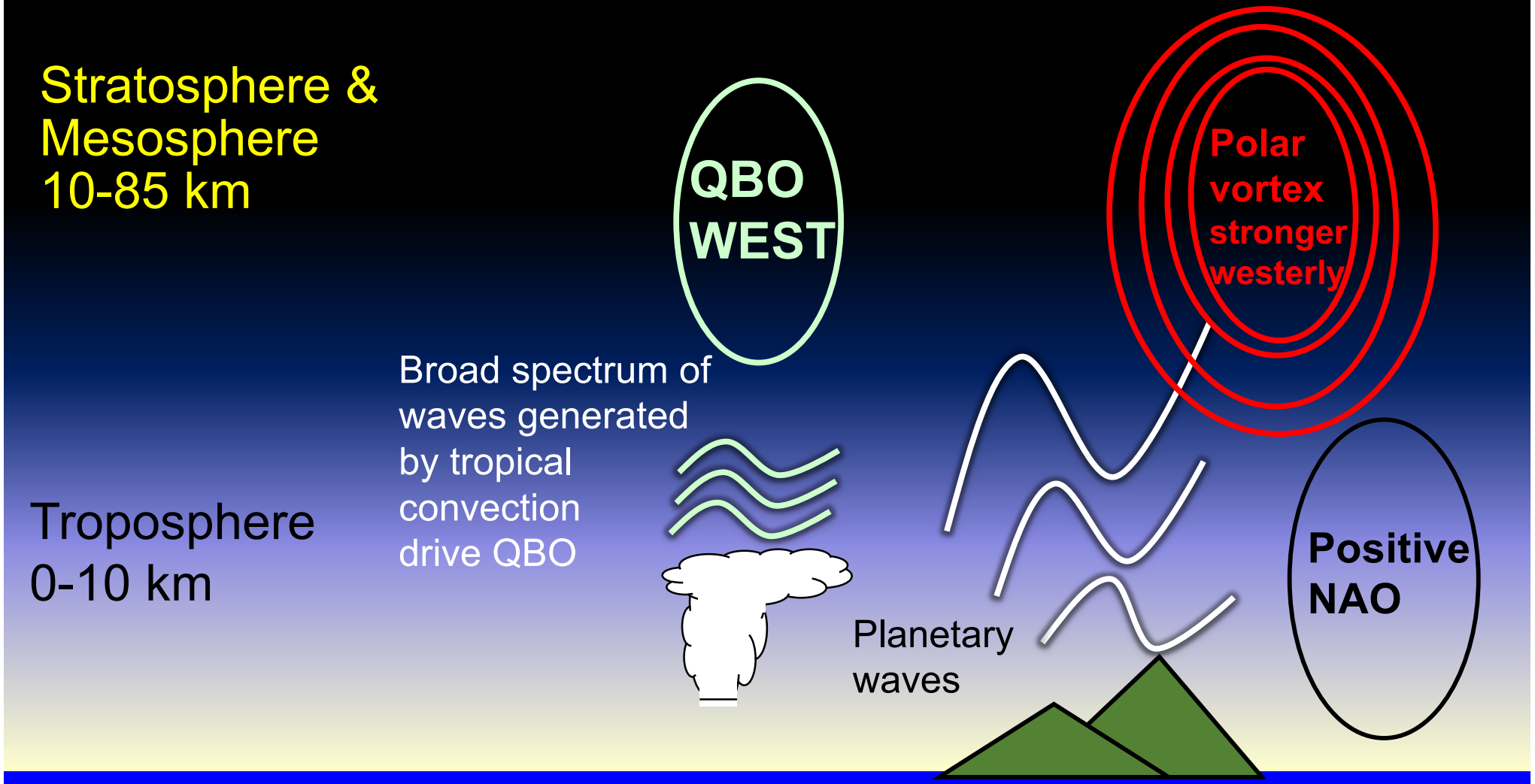
[Visbeck et al., 2003].

The QBO and Why It Is Important for Seasonal Prediction Systems

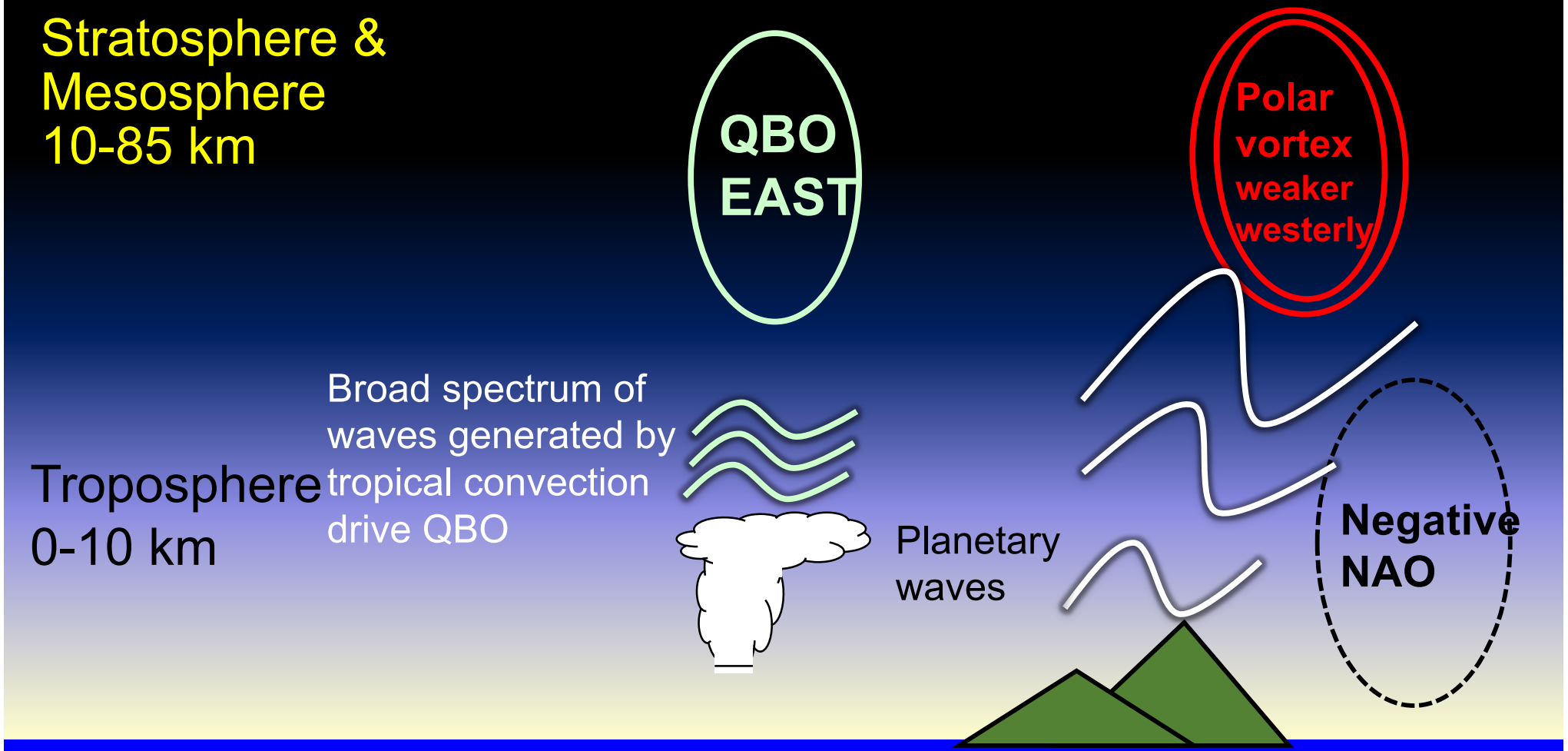


- **28±6 month oscillation of the tropical lower stratosphere**
- **Driven by rich spectrum of convectively generated tropical waves**
  1. Wavenumber-1 Kelvin waves (e.g., the so-called Wallace-Kousky Kelvin wave)
  2. Wavenumber 3-6 mixed Rossby-gravity waves (so-called Yanai waves)
  3. Broad spectrum of small-scale gravity waves
- **Not "spontaneously generated" in most global models** (i.e., hard to model)
- **However, a well-modeled QBO is important for seasonal forecasting systems**
  - QBO modulates stratospheric warmings and downward descent of wind anomalies from the stratosphere into the Arctic troposphere (Holton and Tan 1980; Garfinkel and Hartmann 2011)
  - Changes in the surface NAO are critical to Arctic sea ice prediction (Rigor et al. 2002)
  - This QBO-Arctic NAO teleconnection in turn modulates NH winter responses to important tropical climate indices such as ENSO (Inenson and Scaife 2009)

Impact of Stratospheric Tropical Winds on Seasonal Prediction: The QBO



Impact of Stratospheric Tropical Winds on Seasonal Prediction: The QBO



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Some questions……

- **How good are climate models in predicting stratospheric circulations?**
- Coupled chemistry climate models are best tools for this (see, e.g., Eyring et al., BAMS, 2005)
- Key SPARC activities focusing on this type of question are:
  - Coupled-chemistry climate modeling initiative (CCMI)
  - QBO Intercomparison (QBO-i)
  - Assessing Predictability (SNAP)

  [see Tripathi et al. QJRMS, 2014]

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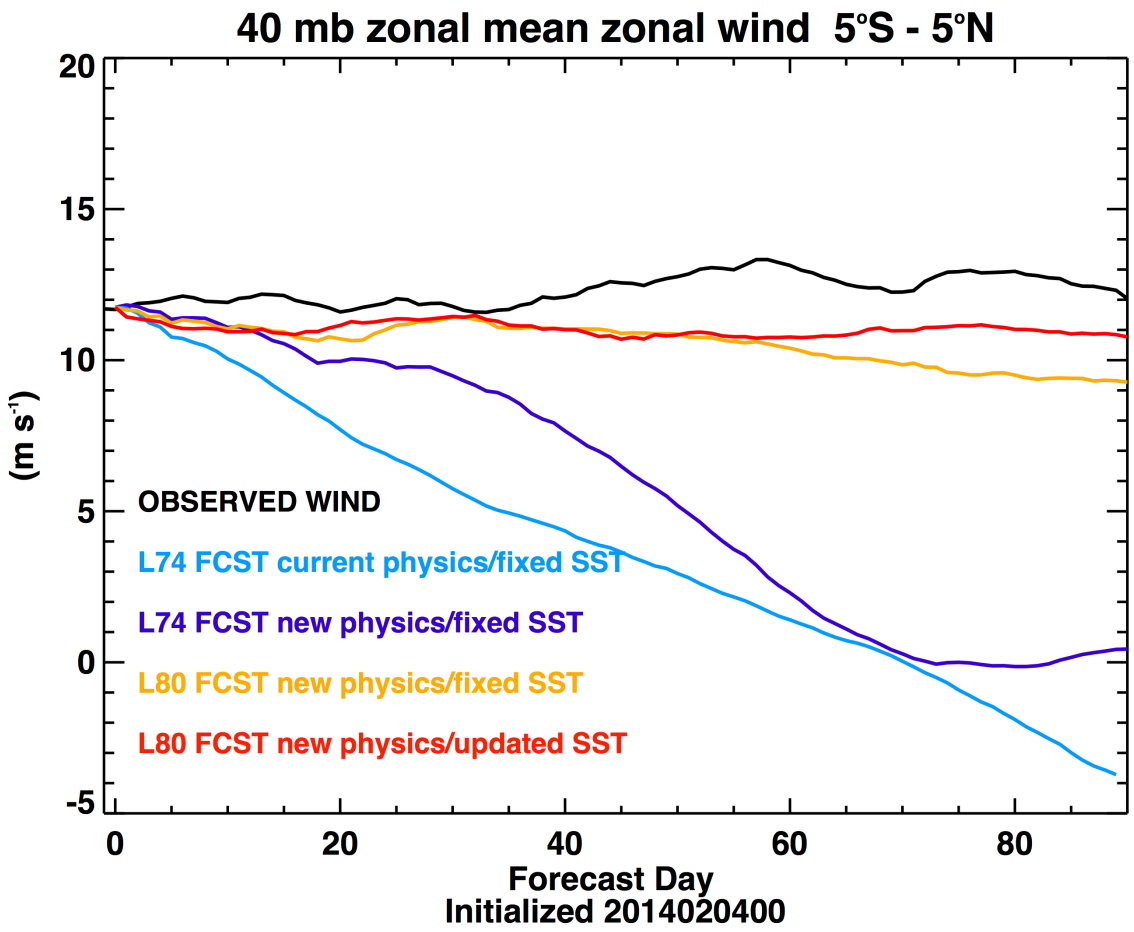
One example…..



Models that cannot produce QBO internally produce persistent easterly flow over the equator in lower stratosphere (blue, purple curves).

Increase in vertical resolution in lower stratosphere ($\Delta z < 1$ km) and modified GWD together produce skillful forecast of QBO westerly winds out to 90 days).

To accurately predict stratospheric circulations over S2S time scales, models need to capture these types of processes.

Quantitative assessments of impact on forecast skill are needed.

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Some questions……

- Is there enough data to evaluate the stratospheric circulations in the models?

- Key SPARC activities:
  - Data Assimilation Working Group
  - SPARC Reanalysis Intercomparison Project (S-RIP)
  - Reanalysis data sets (MERRA2, JRA55, ERA) are probably best tools for this.

AND YET……

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Satellite Data Assimilation

Polar Orbiting Radiances Imagers/Sounders

DMSP F16 SSMIS LAS, UAS, Imager
DMSP F17 SSMIS LAS, UAS, Imager
DMSP F18 SSMIS LAS, UAS, Imager
METOP-A AMSU-A, IASI, MHS
METOP-B AMSU-A, IASI, MHS
NASA EOS Aqua AIRS, AMSU-A
NOAA 15 AMSU-A
NOAA 16 AMSU-A
NOAA 18 AMSU-A, MHS
NOAA 19 AMSU-A, MHS
NOAA NPP ATMS, CrIS, VIIRS
GCOM-W1 AMSR-2
Megha-Tropiques MADRAS, SAPHIR
OceanSat-2
MSG Severi
MSG-II HIR
Jason-1 (SSH, SWH)
Jason-2 (SSH, SWH)
Cryosat2 (SSH, SWH)
Aquarius (Salinity)

Satellite Derived Polar and Geostationary Winds

Coriolis WindSat Ocean Wind Vector
DMSP F16 SSMIS Ocean Wind speed
DMSP F17 SSMIS Ocean Wind speed
DMSP F18 SSMIS Ocean Wind speed
METOP-A AVHRR, ASCAT
METOP-B AVHRR, ASCAT
NASA EOS Aqua MODIS
NASA EOS Terra MODIS, MISR
NOAA NPP VIIRS

Meteosat 9
Meteosat 10
MTSAT
NOAA GOES E
NOAA GOES W
NOAA GOES-R
KMA COMS

GPS Radio Occultation

C/NOFS CORISS
COSMIC FM1-6
GRACE-A
MetOp-A GRAS
MetOp-B GRAS
SAC-C
TerraSAR-X
TanDEM-X
COMS

Other Satellite Products

NASA EOS Aura MLS, HRDLS, OMI
NASA TIMED SABER
NOAA SBUV
JPSS NPP OMPS

MLS and SABER are the only two research satellite instrument missions dedicated specifically for observing temperature and constituents in the stratosphere/mesosphere.

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Satellite Data Assimilation

Aura MLS (O3, T, H2O)
- Launched July 2004
- "Nominal mission lifetime of 5 years, with a goal of 6 years of operation"

TIMED SABER (O3, T)
- Launched December 2001
- "Original mission lifetime of 2 years extended to 5 years"

These two instruments provide important information for validating stratospheric circulations in models either through direct comparisons or through use in stratospheric reanalysis data sets (e.g. MERRA2).

They have exceeded their operational lifetimes, with no plans for replacements AFAIK.

Good news:

A great deal of progress has been made in improving the stratosphere in NWP/DA systems for S2S applications

Bad news:

We may lose key observations needed for forecast initialization and validation

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Summary

- What is the impact of stratospheric circulations on climate/weather prediction?
  - Stratospheric circulations are predictable, and are an importance source of variability on seasonal and interannual time scales.
  - Definite impact of improved stratosphere on short-term NWP skill. More work is needed to assess impact on S2S time scales.

- How good are climate models in predicting stratospheric circulations?
  - Coupled chemistry climate models (CCM's) simulate climatology reasonably well.
  - SPARC activities could provide key information to inform these discussions
  - Models must have necessary physics (scale-aware parameterizations, adequate vertical/horizontal resolution)

- Is there enough data to evaluate the stratospheric circulations in the models?
  - We could be facing a data gap in stratospheric satellite obs soon.

Joint SPARC DA and S-RIP workshop October 23-27 at ECMWF in Reading, UK.