

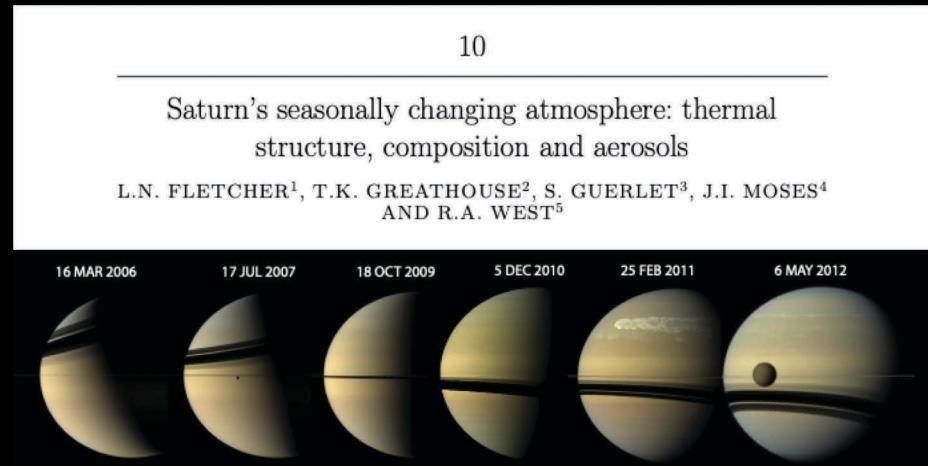
Saturn's Seasonal Atmosphere at Northern Summer Solstice

Proposed Chapter 12 for Cassini at Saturn: The Grand Finale



Premise of Old "Seasonal Saturn" Chapter

- First edition completed in 2014, online in 2015, book published in 2018.
 - Covered Cassini observations 2004-2014, and comparison to ground-based observations 1980-2004.
 - Extensive section 10.2 on temperature evolution and comparison to models (Guerlet, Greathouse, Friedson – limited development since that time).
 - Extensive section 10.3 on chemical observations and comparison to models (mostly Moses, could now add Hue et al. studies).
 - Smaller section 10.4 on clouds and hazes, primarily summarizing pre-Cassini work and scope for updates based on Sromovsky et al.



<https://arxiv.org/abs/1510.05690>

Premise of “New” Chapter – Focus on 2015-2017

- **12.1 Intro/Background:**
 - A review of the 2015 seasonal book chapter, reminding the reader of the open questions.
- **12.2 Seasonal Variations approaching Summer Solstice:**
 - Update to temperature/hydrocarbon seasonal trends since 2014 (CIRS work, Leigh; UVIS work, Tommi).
 - Review UVIS/VIMS/ISS studies of aerosols since 2014 chapter (Bob, Larry)
 - Comparison of end-of-mission thermal field to ground-based TEXES (Sandrine, Tommy).
 - Connection to upper atmosphere & helium derivation (Sandrine, Tommi)
- **12.3 Dynamic events disrupting seasonal evolution:**
 - Disruption of the QZO (Leigh, Sandrine)
 - Hexagon presence in stratosphere (Leigh) - Fold in of polar stratospheric vortices (i.e., those from 75-90°, not the small cyclones to be covered in polar chapter)
- **12.4 Stratospheric chemistry (don't think we need cover the troposphere again):**
 - Updates to chemical models since 2014 (Julie, Vincent)
 - Impact of exogenic inputs (Tommi, Julie)
- **12.5 Open Questions - Looking ahead:**
 - More unanswered questions.
 - What we can do from the ground and JWST.

Chapter Parameters & Guidance

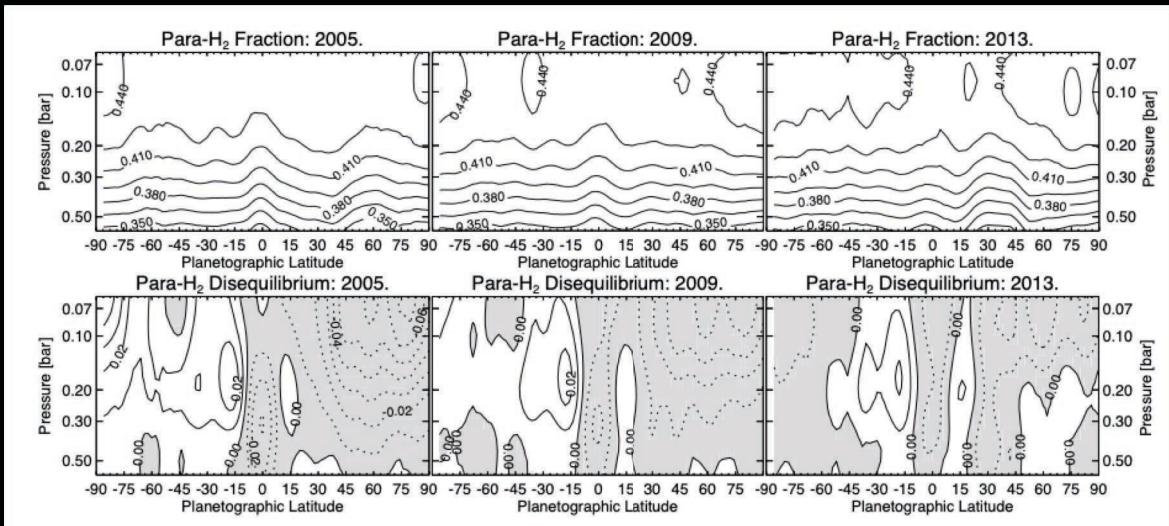
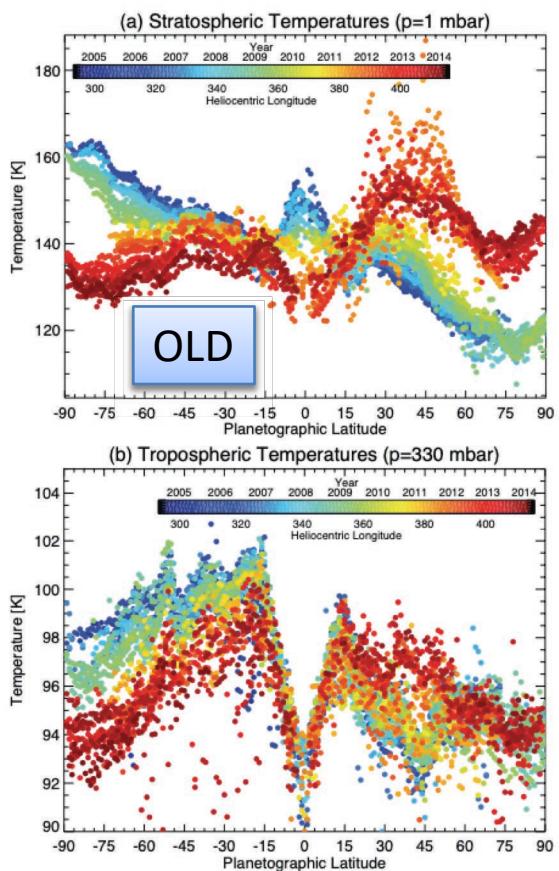
- Deadline: November 30, 2020
- Only include material that will be published by May 2021.
- Length: 10,000 words total, including figure captions
- Figures:
 - 3 color photos/figures to fit in 1.5 pages of color plates, where each page is 276x219 mm.
 - 15 black and white illustrations (graphs, figures, etc)
 - Nominally, 3 B+W photos/images.
- Minimise overlap with chapters on dynamics, upper atmosphere, and polar phenomena where possible.
 - Nothing on ring rain.
 - Limit discussion of circulation to seasonal variability.
 - Avoid discussion of polar cyclones (although larger-scale upper troposphere/stratosphere seasonal change is needed here).

12.2 Seasonal Variations approaching Summer Solstice

This section collates ideas for inclusion in the “seasonal trends” section of Chapter 12, and should focus on things that have changed (or been published since) the end of the last book. This section primarily deals with observations (and radiative models), chemical models to be discussed in 12.4.

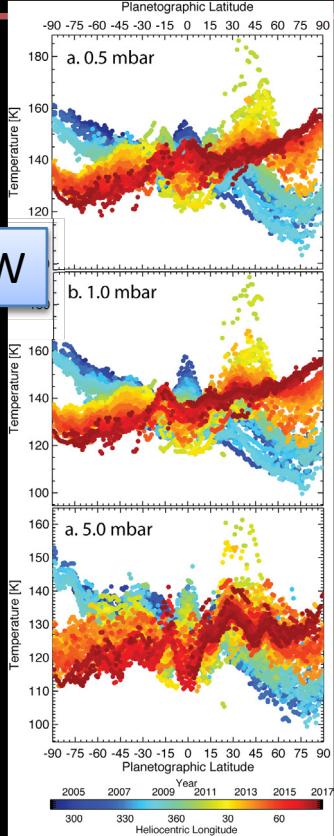
- Temperatures and para-H₂ (CIRS limb and nadir)
- Chemicals (primarily stratosphere) – comparison to models in 12.4.
- Aerosols (ISS, VIMS).

Section 12.2: Seasonal Change

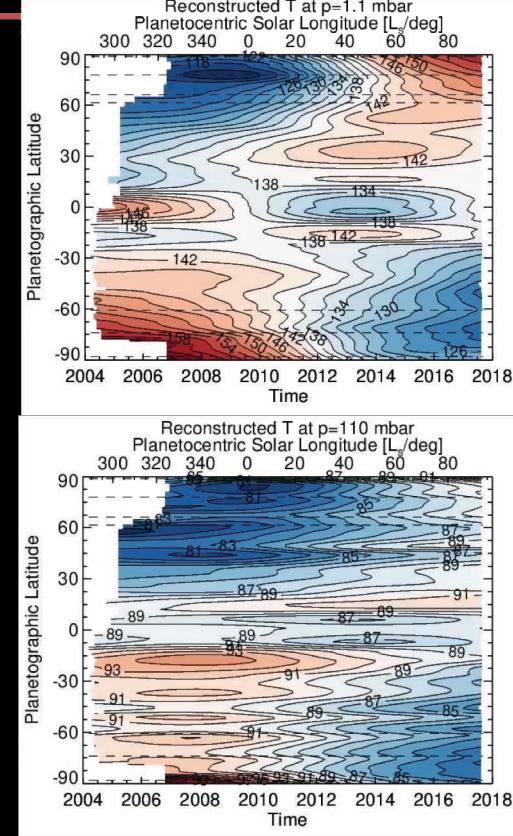
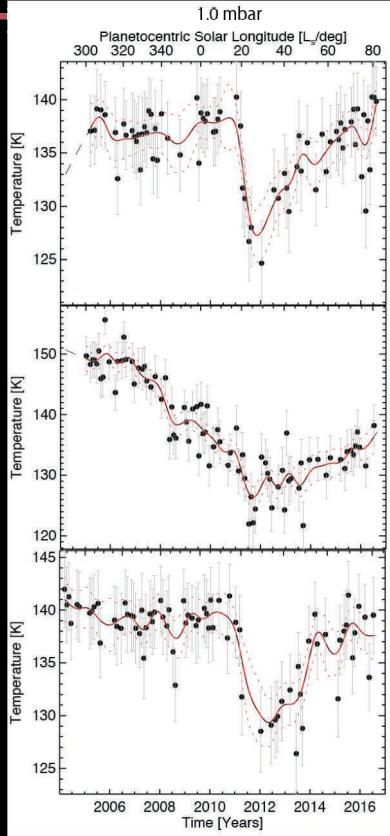


- Leigh to update nadir-T inversions to span 2004-2017 (temperatures from CIRS mid-IR; T and para-H₂ from CIRS far-IR).
 - Work already published in Fletcher++2017,18 but will be refined as new figures (next slide)

Section 12.2: Seasonal Change Update



NEW



Temperature Measurements

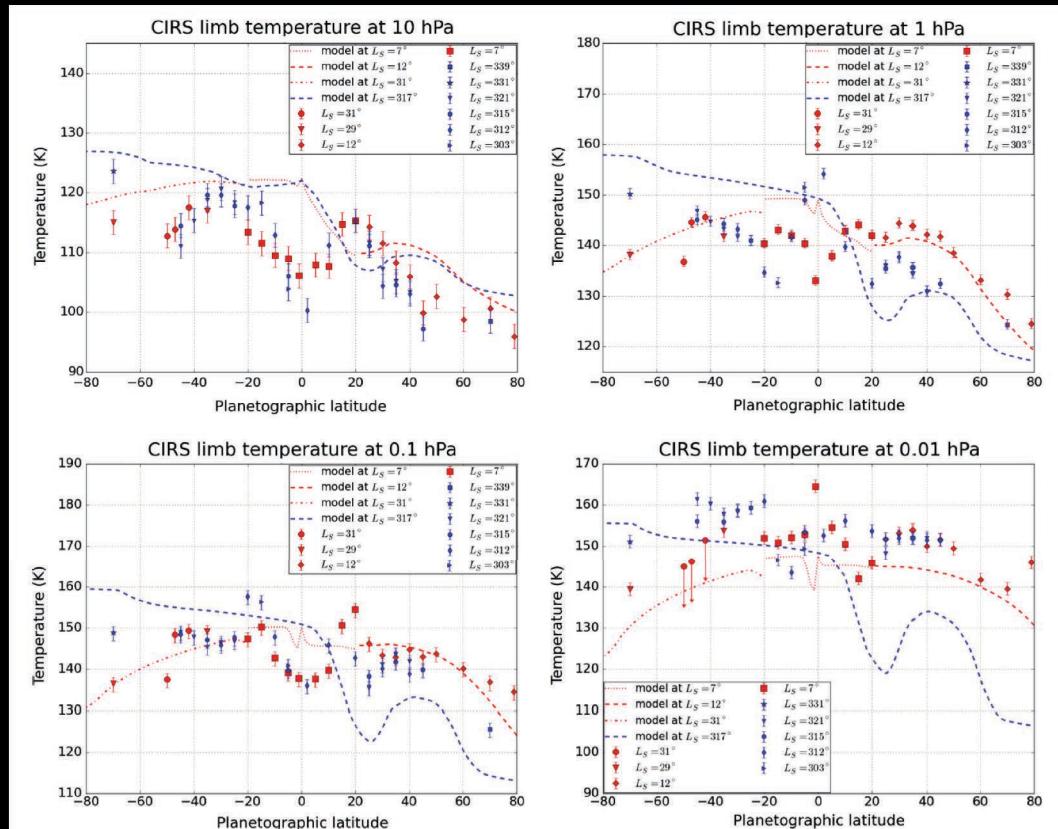
Temperature Interpolation

Temperature Reconstruction

- 12.2 will emphasize availability of complete climate record 2004-2017.
- Discuss implications of cooling/warming trend at each latitude.
- Note largest stratospheric changes at poles, and dynamics of equator.
- Include comparison to Brown et al. (2020) thermosphere gradients.

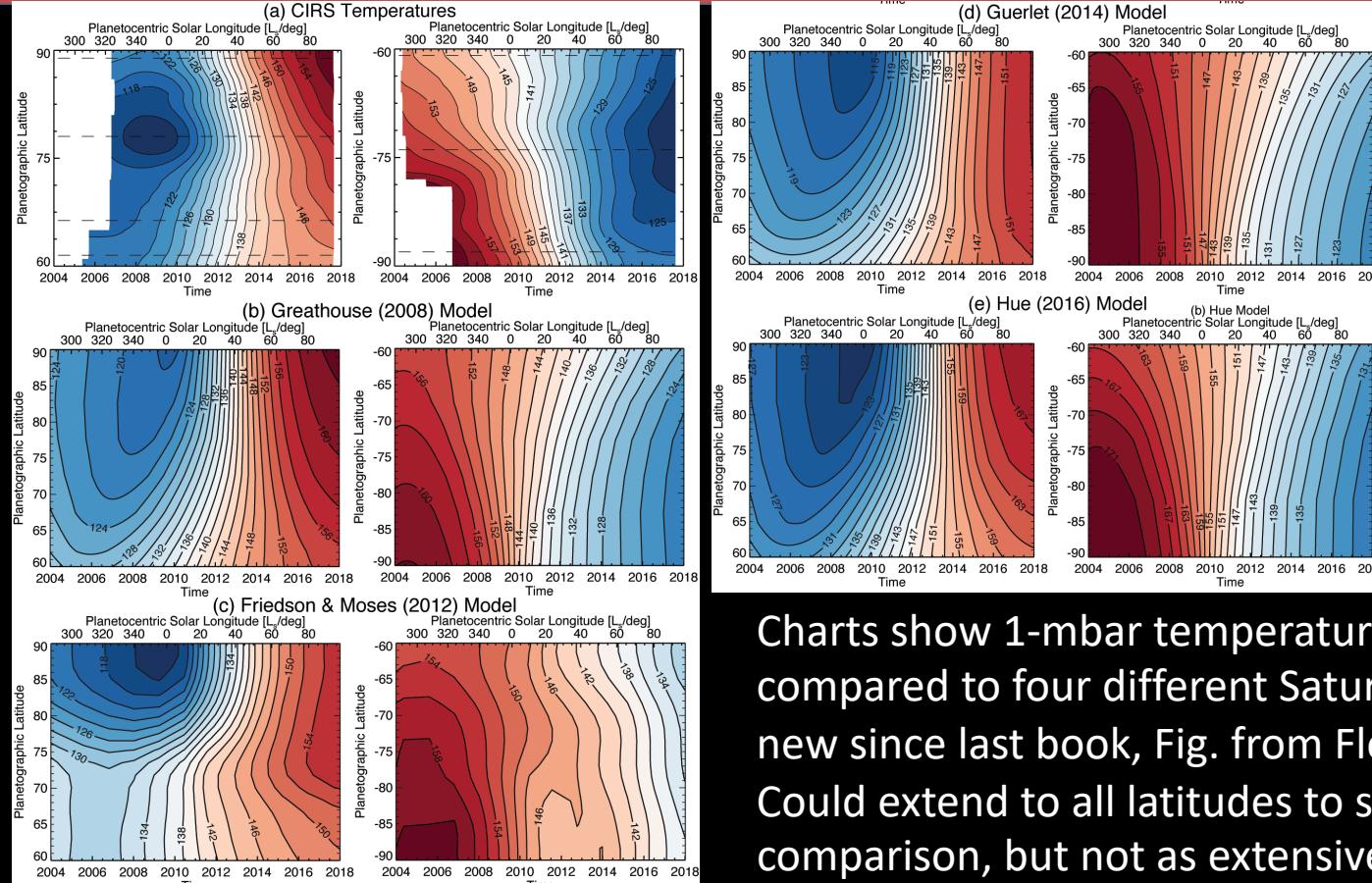
Section 12.2: Limb-Sounding Temperature Updates

- Sylvestre et al. (2015) updated stratospheric temperature trends from CIRS limb-sounding.
- Aim to describe comparison to nadir-sounding results and new insights beyond 2014 Saturn Chapter.
- Still doesn't cover anything >2015 – *any updates?*



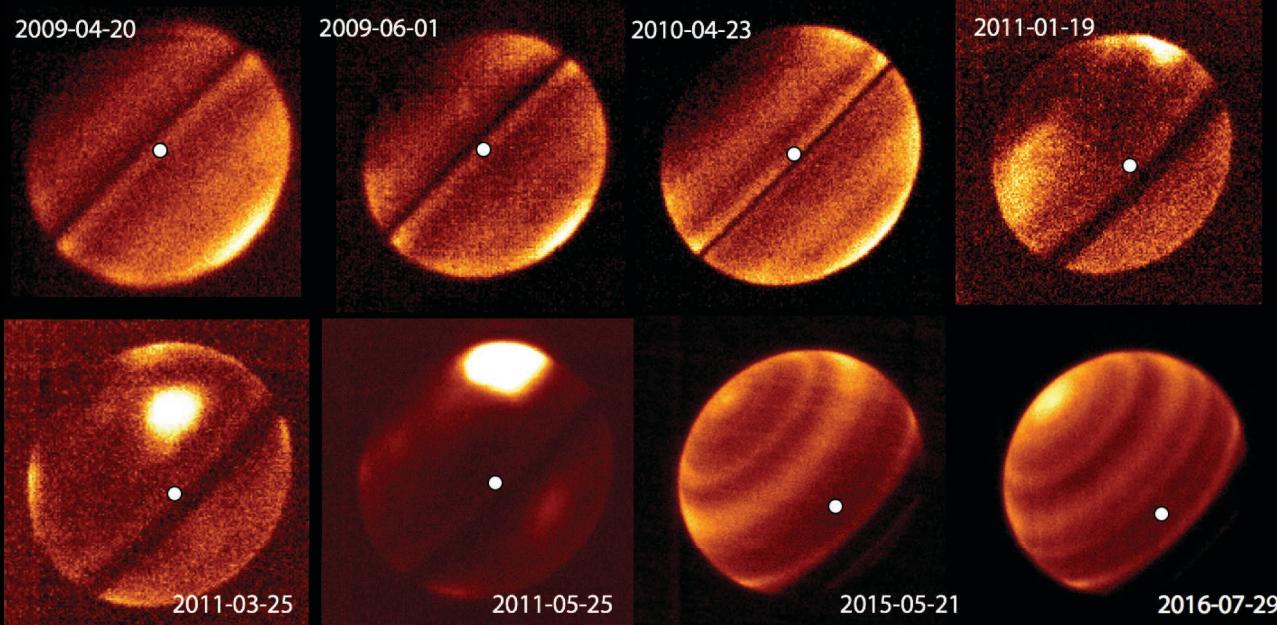
[http://dx.doi.org/10.1016/
j.icarus.2015.05.025](http://dx.doi.org/10.1016/j.icarus.2015.05.025)

Section 12.2: Comparison to Models



Charts show 1-mbar temperature at the poles compared to four different Saturn models (one new since last book, Fig. from Fletcher+2018). Could extend to all latitudes to show model-data comparison, but not as extensive as last book.

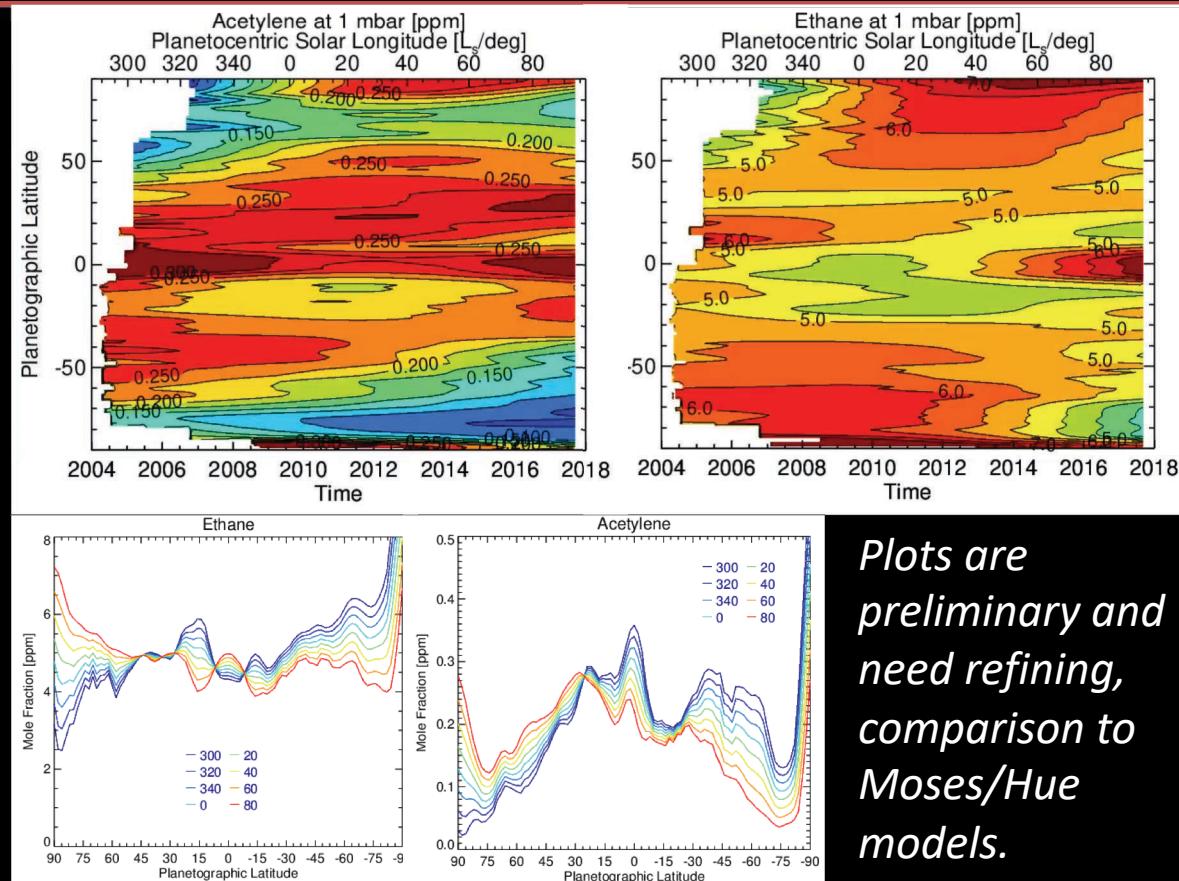
Section 12.2: Comparison to Ground-Based



- Aim to include comparison of Cassini T(p) record to ground-based imaging (e.g., VLT, left) and spectroscopy (e.g., Gemini/TEXES).
- Demonstrates that seasonal studies can continue post-Cassini.

Section 12.2: Stratospheric Chemical Changes

- Old Book presented CxHy profiles in comparison to Moses et al. models.
- New info to include:
 - Nadir analysis of ethane/acetylene (Fletcher+2018, right, only polar details published so far) extended to all latitudes.
 - Updates from limb analysis (Sandrine?).



Section 12.2: Tropospheric Chemical Changes?

- No further papers (TBD) discussing changes to PH₃ and NH₃ as a function of latitude and time – likely to be omitted from new chapter.

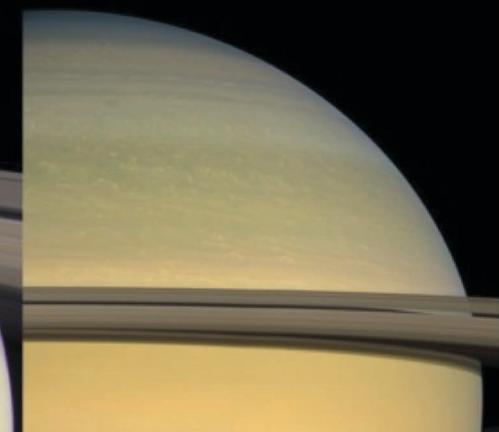
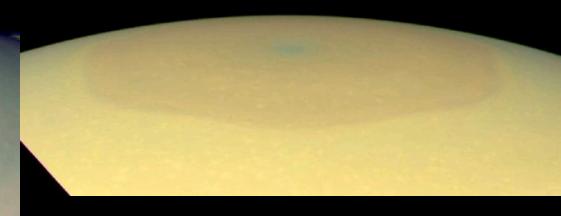
Section 12.2: Aerosol Changes

- Cassini aerosol studies have been rather thin.
- ISS imaging of changing colours (most notable at poles)
 - *Has this been published anywhere?*
- VIMS assessment of cloud structure from Sromovsky et al. (others?)
 - *Hasn't really dealt with seasonal change yet.*
- Chapter 12 is the only one to deal with clouds, so there's scope for a “non-seasonal” short review of what we have to date.

November 2012



September 2016



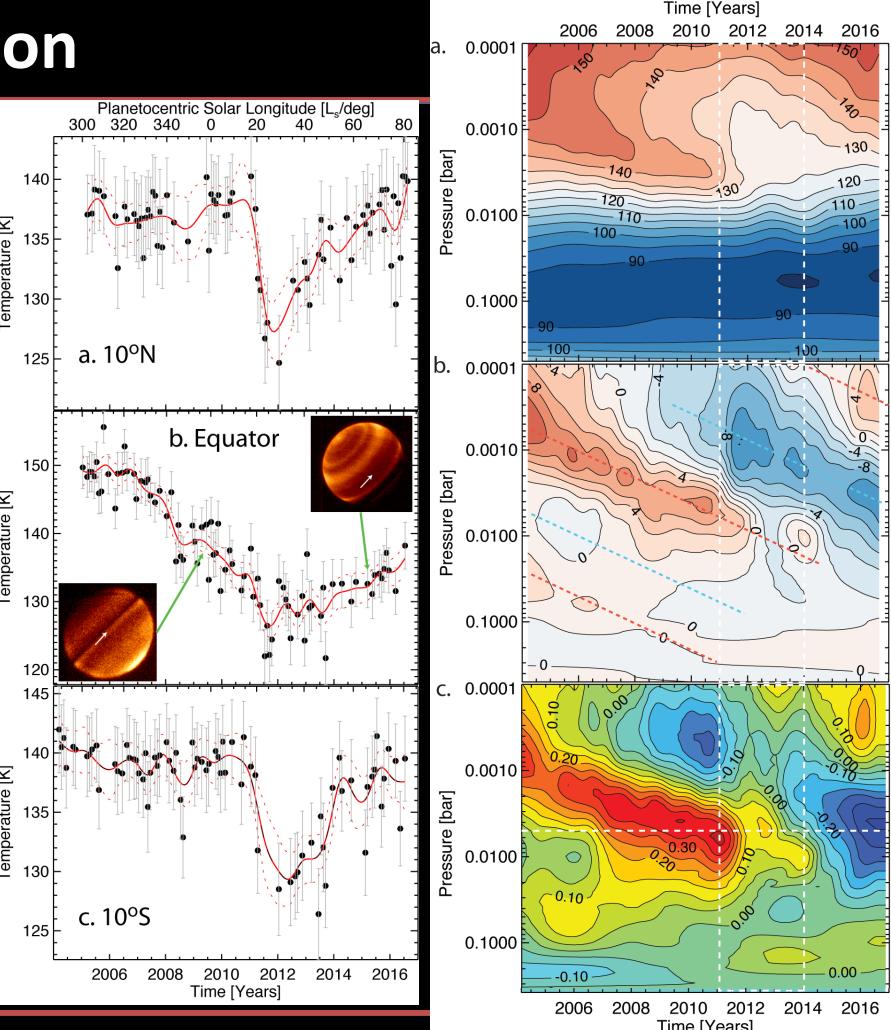
12.3 Dynamic events disrupting seasonal evolution

This section looks at dynamic phenomena that are perturbing the slow seasonal evolution. It will be brief and refer to other chapters where the dynamical theory is described in more depth.

- Polar vortices (e.g., 75-90 deg.)
- Equatorial Oscillation
- Others?

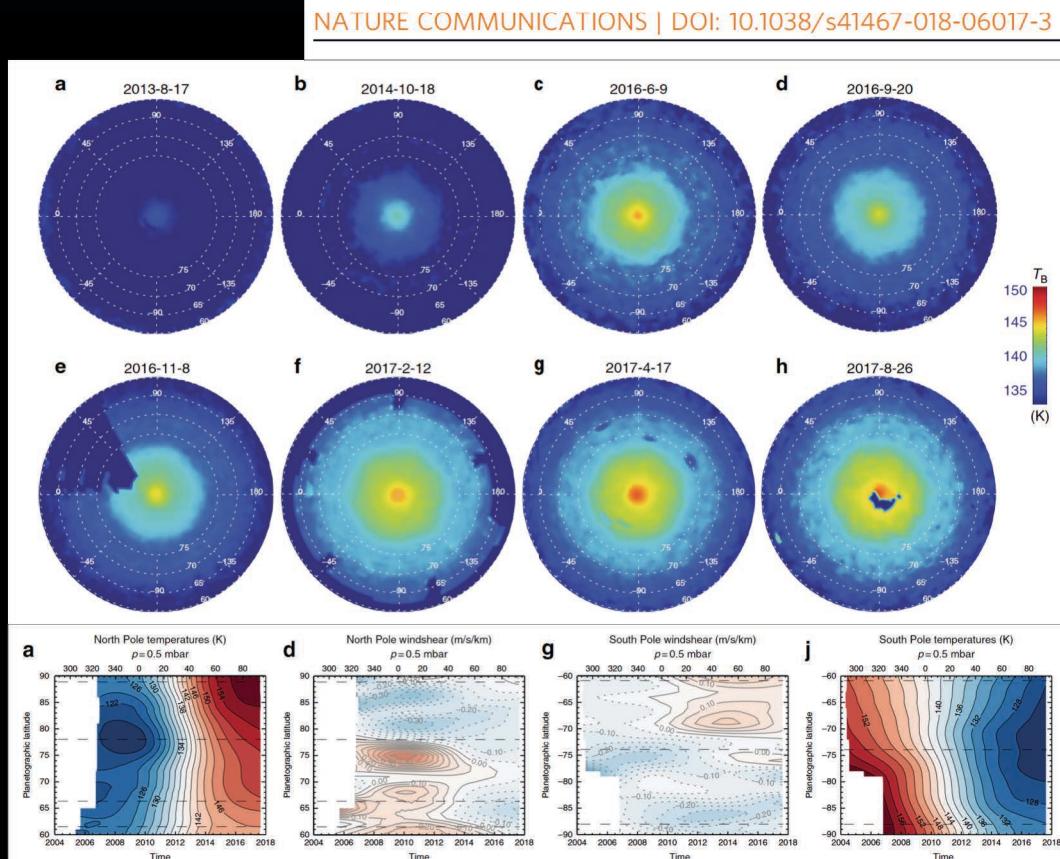
12.3: Saturn Equatorial Oscillation

- Disruption of oscillation by northern storm 2011-2013 (Fletcher+2017, Guerlet+2017).
- Returned to pre-storm trends by Cassini EOM?
- Predictions for oscillation appearance beyond 2017 and comparison to more recent ground-based data.



12.3: Saturn Polar Warming/Cooling

- **Clarify:** we mean the large, seasonal 75-90° vortices in the upper troposphere and stratosphere, not the 88-90° cyclones.
- Changes to temperatures & abundances are larger than expected from seasonal trends alone:
 - Complications over separating uncertain aerosol properties from residual-mean circulation.



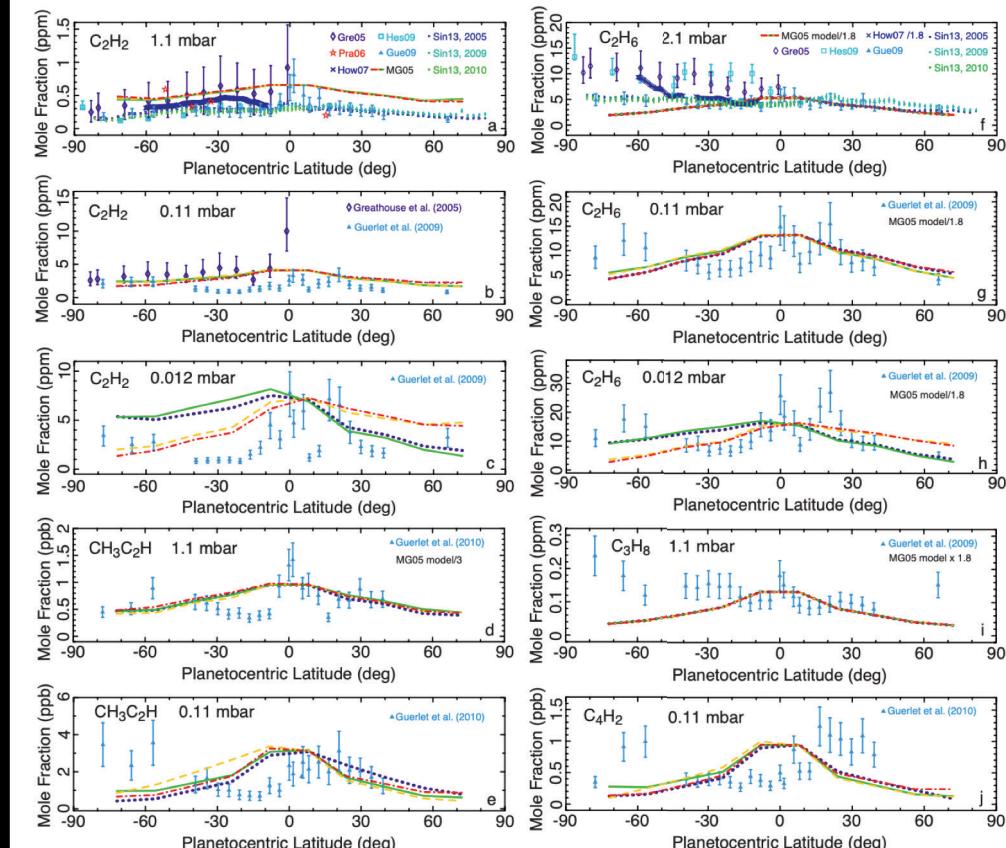
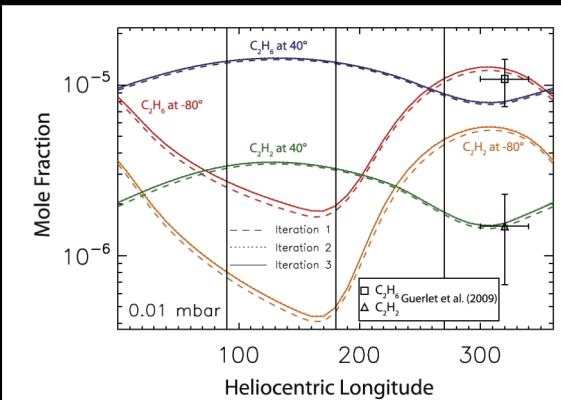
12.4 Advances in Chemical Modelling

This section explores any recent advances in seasonal chemistry modelling. Last Book focused on Moses et al. work, new insights from Hue et al., Koskinen et al.

We could potentially move the chemical comparison part of 12.2 to this section to avoid too much repetition, and need to be mindful of chemistry in “upper atmosphere” chapter.

12.4 Stratospheric Neutral Chemistry

- Old Book:
 - Results from multiple authors (right) compared to Moses et al. models as a function of season.
 - No need to update?
- New Book:
 - Focus on advances since 2014, esp. feedback study of Hue et al. 2016 (below)?
 - Generate 2D (latitude/time) plots for comparison with data.



12.4 Stratospheric Ion-Neutral Chemistry

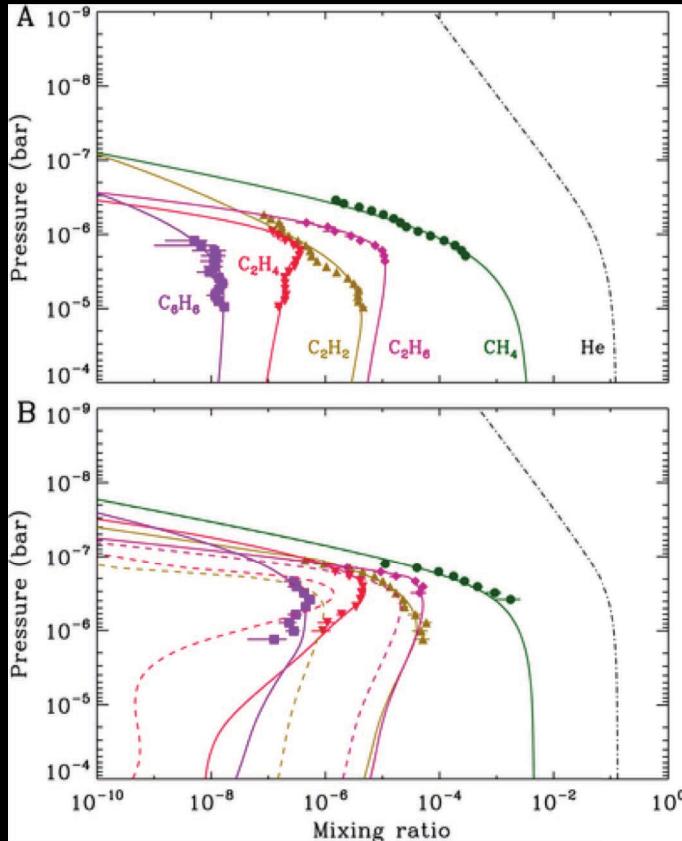
- Benzene detection (and other CxHy/haze) from UVIS/CIRS study.
- Comparison to photochemical models suggests need for ion-neutral chem.
 - *Any further updates?*
 - *Will this be covered elsewhere?*

Research Letter

The detection of benzene in Saturn's upper atmosphere

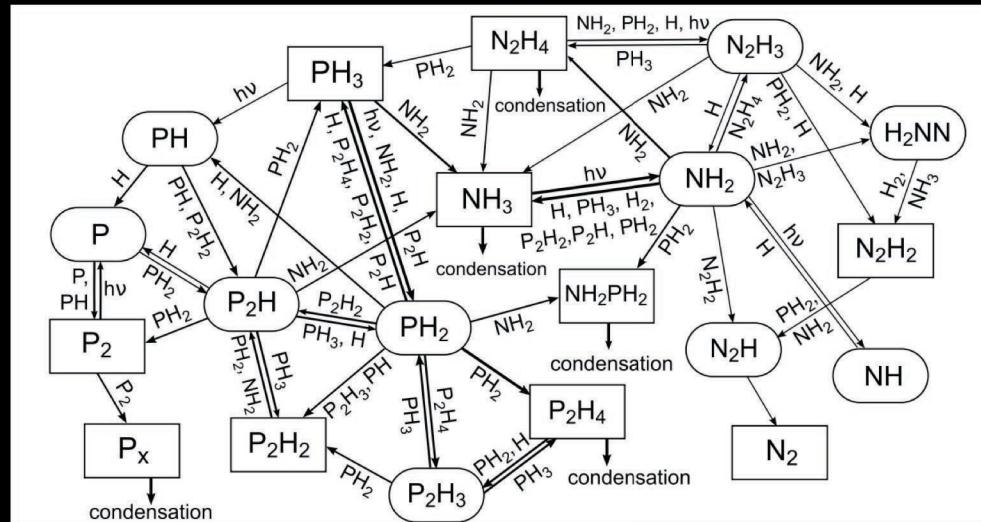
T. T. Koskinen ✉, J. I. Moses, R. A. West, S. Guerlet, A. Jouchoua

First published: 04 August 2016 | <https://doi.org/10.1002/2016GL070000> | Citations: 15



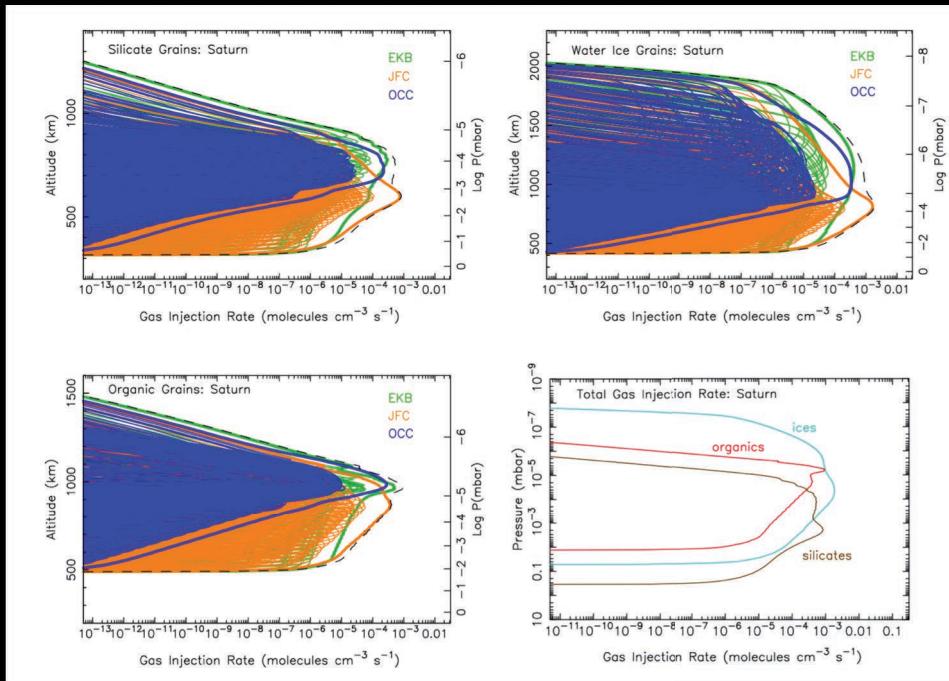
12.4 Tropospheric Chemistry

- Well-covered in 2014 chapter and no updates since then (unless Moses et al. PH3 work published by May '21).



12.4 Exogenic Materials

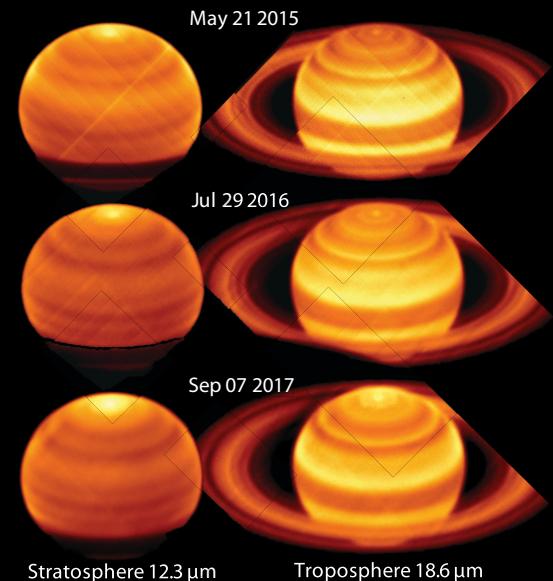
- Some coverage in Old Book, and no observational evidence of seasonal change, but will it be covered elsewhere?
- Include some discussion of Moses & Poppe dust grain ablation modelling (2017, right).
 - *Or will this be covered elsewhere?*
- Discuss connection between water and Enceladus plume (Cavalie++2019).



12.5 Open Questions and Looking Ahead

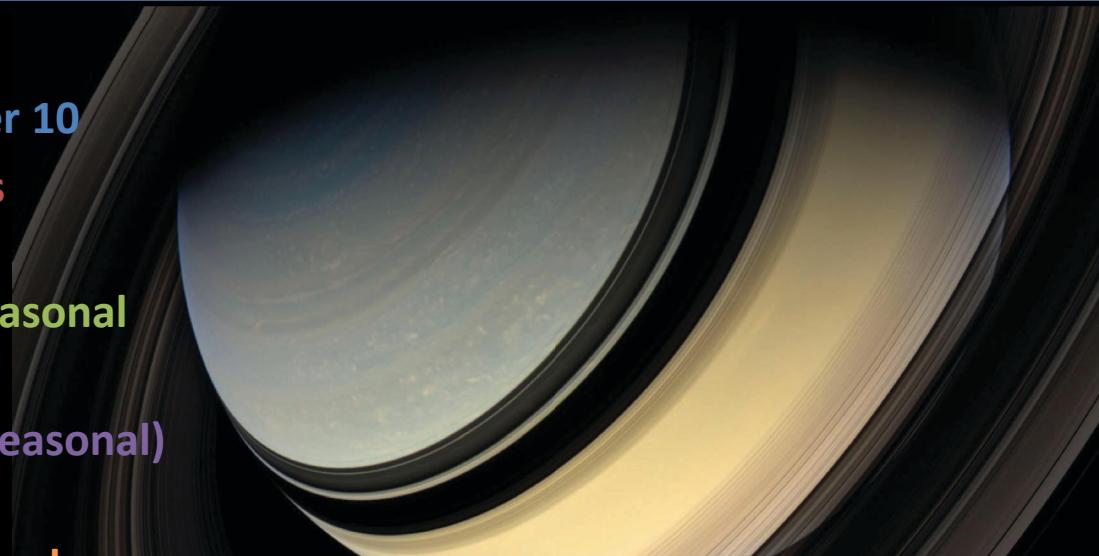
Final section deals with look beyond summer solstice – continued observations 2017-2021 with observatories (VLT, Gemini, Hubble); proposed plans with JWST; and opportunities with future missions/observatories.

Can be relatively short, as many of the open questions are similar to the Old Chapter.



Summary – Chapter 12

- **12.1 Overview of Old Book Chapter 10**
- **12.2 Observed Seasonal Variations approaching Summer Solstice**
- **12.3 Dynamic events disrupting seasonal evolution**
- **12.4 Advances in (Seasonal/Non-Seasonal) Chemical Modelling**
- **12.5 Open Questions - Looking ahead beyond Solstice**



Aim to write a chapter that focuses on seasonal phenomena up to summer solstice, alongside advances in troposphere/stratosphere modelling.

Library of references: <https://ui.adsabs.harvard.edu/public-libraries/QTuyjBTXS8aYEy9mNDlbg>